Radical Change in Energy Intensive UK Industry

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Signed……

Abstract

Managing energy demand is essential to energy security and climate change mitigation. The industrial sector accounts for over a fifth of UK primary energy demand and greenhouse gas emissions. Energy intensive industry is uniquely restricted in the way it uses energy and emits greenhouse gasses. In this thesis, the potential of radical measures to achieve significant energy demand reduction and emissions abatement in UK energy intensive industry is assessed.

Adopted is a multidisciplinary approach combining thermodynamic and techno-economic analysis techniques. Bottom-up assessments are applied to key energy intensive sectors of industry to capture the diverse and interactive array of technological characteristics invisible from a top-down perspective. Detailed projection models are built to design and analyse technology roadmaps for the sectors out to 2050.

In an illustrative roadmap assessment, the technological pathways of radical process transition and carbon sequestration were each shown to achieve about 80% abatement in 2050 from 1990 emissions levels. Radical process transition achieved greater abatement before 2030 and this was reflected in lower cumulative emissions over the full period. Higher risk is associated with carbon sequestration from its reliance on timely access to CO_2 transport and storage technology to compensate for lower short-medium term abatement. Although, combining carbon sequestration with high levels of biomass combustion indicated the largest potential abatement to 2050.

Abatement economics in the iron and steel sector are notably sensitive to resource costs and the carbon trading price. The carbon trading price influences relative production costs in favour of higher abating pathways, but increases absolute costs. This signals the need for supportive policy measures that accelerate technology development and deployment while mitigating the risk of the carbon trading price to competitiveness. Some carbon capture technologies reduce relative production cost even in the absence of a carbon price, but this excludes the cost of CO_2 transport and storage. Meanwhile, radical process transition pathways have a higher dependence on the future prices of natural gas, electricity, and scrap.

Future work should focus on expanding the economic appraisal to other sectors and to indirect costs, as well as incorporating wider material efficiency strategies and running different future scenarios.

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Lastly, I would like to thank my family and friends for their moral support throughout.

This thesis is dedicated to the loving memory of Dr. James Griffin.

"If we dig precious things from the land, we will invite disaster."

Translation of a Hopi prophecy sung in Koyaanisqatsi: Life Out of Balance

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List of abbreviations

Abbreviation	Meaning
2007u	Updated 2007
AC	Abatement cost
ASU	Air separation unit
BAT	Best available technology
BAU	Business as usual
BCA	British Cement Association
BCG	Boston Consulting Group
BF	Blast furnace
BF-BOF	Blast furnace-basic oxygen furnace route
BF-EAF	Blast furnace-electric arc furnace route
BFG	Blast furnace gas
BF-OHF	Blast furnace-open hearth furnace route
Bio-CCS	Biomass with CCS
BIS	Department for Business, Innovation and Skills
BLA	British Lime Association
BOF	Basic oxygen furnace
BOFG	Basic oxygen furnace gas
BPT	Best practice technology
BT-CCS	Biomass process transition with CCS
C	Carbon
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CAPEX	Capital expenditure
CC	Continuous casting
CCAs	Climate Change Agreements
CCC	Committee on Climate Change
CCF	Cyclone converter furnace
CCL	Climate Change Levy
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture, use and storage
C-fix	Carbon fixation
CH_4	Methane
CHP	Combined heat and power
CO	Coke oven
CO_2	Carbon dioxide

Abbreviation	Meaning
CO_2e	Carbon dioxide equivalent
COG	Coke oven gas
CO_{Total}	Total coke oven production
CSA	Calcium sulfoaluminate
CSI	Cement Sustainability Initiative
CT-CCS	Coal process transition with CCS
CV	Calorific value
DECC	Department of Energy and Climate Change
Defra	Department of Environment, Food and Rural Affairs
DG	Dash for gas
DG-CCS	Dash for gas with CCS
DRI	Direct reduced iron
DUKES	Digest of United Kingdom Energy Statistics
EA	Energy Accounts
EAF	Electric arc furnace
EAS	Energy Audit Series
ECSC	European Coal and Steel Community
ECUK	Energy Consumption in the UK
EE-MRIO	Environmentally extended multi-region input-output model
EF	Emission factor
EMR	Electricity Market Reform
ET	Existing process transition
ETE	Ethanol-to-ethylene
ETP	Energy Technology Perspectives
ETS	Energy trading system
ETSU	Energy Technology Support Unit
FBK	Fluidised bed kiln
Fe	Iron
FFT	Fuel and feedstock transition
FLT	First law of thermodynamics
FS	Finished steel
FSP	Finished steel production
FT	Fischer-Tropsch
GCV	Gross calorific value
GDP	Gross domestic product
GER	Gross energy requirement
GGBFS	Ground granulated blast furnace slag

Abbreviation	Meaning
GhG	Greenhouse gas
GHGI	Greenhouse gas inventory
GNR	Getting the Numbers Right
GRA	Grid rolling average
GT	Gas process transition
GT-CCS	Gas process transition with CCS
GVA	Gross value added
H	Hydrogen
H_2	Dihydrogen
H_2O	Hydrogen dioxide
HHV	Higher heating value
HR	Hot rolling
HRS	Hot-rolled steelmaking
IC	Ingot casting
IDA	Index Decomposition Analysis
IEA	International Energy Agency
IEAGHG	IEA Greenhouse gas project
IFIAS	International Federation of Institutes of Advanced Studies
IISI	International Iron and Steel Institute
I-O	Input-output
IoP	Index of production
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
ISSB	Iron and Steel Statistics Bureau
L	Level
LCA	Lifecycle analysis
LCICG	Low Carbon Innovation Co-ordination Group
LD	Linz and Donowitz
LHV	Lower heating value
LMDI I	Log mean Divisia index I
LS	Liquid steelmaking
MAC	Marginal abatement cost
MDEA	Methyl diethanolamine
MDEA/Pz	Methyl diethanolamine with Piperazine
MEA	Methyl ethanolamine
Mn	Manganese
MOE	Molten oxide electrolysis

Abbreviation	Meaning
MPA	Mineral Products Association
MPPs	Major power producers
MTO	Methanol-to-olefins
N	Nitrogen
N_2	Nitrogen gas
NAEI	National Atmospheric Emissions Inventory
NCV	Net calorific value
NER	Net energy requirement
NEU	Non-energy use
NGCC	Natural gas combined cycle
NH_3	Ammonia
NNFCC	National Non-Food Crops Centre
NO_x	Nitrous oxide
NPV	Net present value
O	Oxygen
O_2	Oxygen gas
OCM	Oxidative coupling of methane
OHF	Open hearth furnace
ONS	Office for National Statistics
OPC	Ordinary Portland Cement
OPEX	Operational expenditure
OPG	Other petroleum gas
PA	Process analysis
PER	Process energy requirement
PFA	Pulverised fly ash
PI	Purchases Inquiry
PLA	Poly-lactic acid
POX	Partial oxidisation reactor
PRODCOM	Products of the European Community
PSA	Pressure swing absorption
R&D	Research and development
RA	Reasonable action
RA-CCS	Reasonable action with CCS
RD&D	Research, development and demonstration
RET	Radical existing process transition
RHI	Renewable Heat Incentive
RT	Radical process transition

Abbreviation	Meaning
RT-EP	Radical transition with existing processes
S	Sulphur
SCMs	Supplementary cementitious materials
SEA	Statistical energy analysis
SEC	Specific energy consumption
SEC_p	Simple primary specific energy consumption
SEEA	System of Environmental Economic Accounts
SERT	Sustainable Energy Research Centre
SFS	Semi-finished steelmaking
Si	Silicon
SIC	Standard industrial classification
SLT	Second law of thermodynamics
SO_2	Sulphur dioxide
SP	Sinter plant
tb	Tonnes of brick
tc	Tonnes of Ordinary Portland cement
tcs	Tonne of crude steel
tdc	Tonne of dry coke
tdri	Tonnes of direct reduced iron
tg	Tonnes of glass
TGR-BF	Top-gas recovery blast furnace
thm	Tonnes of hot metal
thrs	Tonnes of hot-rolled steel
thvc	Tonnes of high value chemical
TINA	Technology Innovation Needs Assessment
tl	Tonnes of lime
tls	Tonnes of liquid steel
TP	Technology Portfolio
tpb	Tonnes of paper and board
TPED	Total primary energy demand
TPES	Total primary energy supply
TRT	Top-gas recovery turbine
ts	Tonnes of sinter
tsfs	Tonnes of semi-finished steel
TSU	True steel use
UED	Usable Energy Database
UK	United Kingdom

Abbreviation	Meaning
UKERC	UK Energy Research Centre
ULCOS	Ultra Low CO_2 Steelmaking
ULCOS	Ultra Low CO_2 Steelmaking
UNFCCC	United Nations Framework on Climate Change
USA	United States of America
V4	Version 4
VP	Value of production
VPSA	Vacuum pressure swing absorption
WBCSD	World Business Council for Sustainable Development

Nomenclature

Symbol	Definition
atm	Atmosphere
B	Exergy
B_{ch}	Chemical exergy
b_{ch}	Specific chemical exergy
b_d	Specific exergy destruction
$B_{destruction}$	Exergy destruction
b_i	Specific exergy input
B_{inputs}	Exergy inputs
b_j	Specific exergy output
$B_{outputs}$	Exergy outputs
B_{ph}	Physical (Thermal) exergy
b_{th}	Specific thermal exergy
$B_{products}$	Exergy products
$B_{transit}$	Transit exergy
B_{wastes}	Exergy wastes
C	Energy or emissions pathway from crosscutting measures
C_p	Heat capacity
c_p	Specific heat capacity
E	Energy (Energy or Emissions, with regard to pathways)
E_{inputs}	Energy inputs
$E_{outputs}$	Energy outputs
E_p	Primary energy input
$E_{products}$	Energy products
E_{wastes}	Energy wastes
FV	Future value
GJ	Gigajoule
H	Enthalpy
h	Specific enthalpy
H_c	Enthalpy of combustion
h_{ch}	Specific chemical enthalpy
H_{ph}	Enthalpy from physical phenomena
h_{th}	Specific thermal enthalpy
I	Irreversibility
I	Initial investment
J	Joule
K	Kelvin

Symbol	Definition
kg	Kilogram
kJ	Kilojoule
kmol	Kilomole
kt	Kilotonne
kWh	Kilowatt hour
m	Mass
m_i	Input mass
m_j	Output mass
MJ	Megajoule
Mt	Megatonne
n	Number of years in project
N	Total years of project
η	Energy efficiency
η_{carnot}	Carnot efficiency
NPV	Net present value
P	Energy or emissions pathway
p	Pressure
p_0	Ambient pressure
PJ	Petajoule
PV	Present value
PVF	Present value factor
Q	Heat energy
q	Specific heat energy
Q^B	Heat exergy
q_b	Specific heat exergy
R	Universal gas constant (or energy/emissions pathway of replacement technologies)
r	Discount rate
R	Annual revenue
R	Gas constant
S	Entropy
$S_{isolated}$	Entropy of an isolated system
S_{ph}	Entropy generated from physical phenomena
T	Temperature
t	Tonne
T_0	Ambient temperature
TJ	Terajoule

Symbol	Definition
U	Internal energy
U_{ch}	Chemical energy
U_{th}	Thermal energy
V	Volume (or 'aggregate variable', with regard to of decomposition analysis)
v_m	Mean volume
W	Work energy
W^B	Work exergy
x	Mole fraction (or 'change factor' in decomposition analysis; or proportion of sector production in pathway analysis)
β	Chemical exergy to net calorific value ratio
γ	Coefficient of non-ideal behaviour
ε	Reciprocal of energy transformation efficiency
Θ	Thermodynamic quality
ψ	Exergy efficiency
ψ_s	Simple exergy efficiency

1 Introduction

Human development over the past few centuries has been greatly accelerated by the effective utilisation of energy. Energy underpins the functioning of modern lives and the economic systems they constitute. Energy does not itself have value but is the ability to affect change and thereby deliver valuable services. These services are ubiquitous and the products of well-established industrial systems, the presence of which is invisible to most people and easily taken for granted.

Most of the energy resources on which the present system depends are unevenly distributed around the world and are depleting. Furthermore, the processes that convert energy from these resources emit gasses that harm the environment and could alter the global climate system. The international community recognises these issues and efforts are being made to abate emissions and transition to a more sustainable energy system. To realise this future will require unprecedented technological and behavioural change across all parts of the global economy.

1.1 Energy security and climate change

Fossil fuels coal, oil and natural gas are embedded in the energy system, accounting for some 80% of global primary energy demand (IEA 2014b). Energy security is the assurance of affordable energy supply and thus translates to the availability and cost of fossil fuels. Energy policy of developed nations was fundamentally influenced by two oil price shocks in the 1970s which prompted action to curb demand and tackle dependency on fuel imports. In the UK prices plummeted in the 1980s from the exploitation of North Sea oil and gas, but reserves have since diminished and global energy prices surged again in recent years (Pearson and Watson 2012). Global energy demand is predicted to double by 2040 with the general price of fossil fuels increasing by nearly 50% (IEA 2014c). Presently the UK is dependent on fossil fuels for 90% of its primary energy demand (DECC 2013a).

Fossil fuels are formed over hundreds of millions of years as a result of geologic processes acting on the remains of dead organic matter (Merriam-Webster 2014). Their combustion yields carbon dioxide (CO_2), which is a greenhouse gas (GhG). Greenhouse gasses are so-called because they trap the Sun's energy as infrared radiation within the Earth's atmosphere, leaving average surface temperatures higher than they would otherwise be (IPCC 2013). This is the greenhouse effect and is a natural process on which humankind depends. However, it is evident that the scale of anthropogenic GhG emissions is such that it is causing global warming. Atmospheric concentrations of CO_2 have risen by 40% since pre-industrial times and to a level unprecedented in at least the last 800,000 years (ibid.). As emissions have accelerated, the rate of increase in global average temperatures has also risen from about 0.1°C per decade over first half of the twentieth century to nearly 0.2°C over the period 1951-2012 and 0.26°C over the period 1979-

2012 (ibid.). Limiting global warming to 2°C above pre-industrial levels has long been acknowledged as a sensible target for avoiding dangerous and unpredictable climate change (Rijsberman and Swart 1990).

In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) it was recommended that GhG emissions must reduce 50-85% by 2050 to prevent a rise of 2-2.4°C (IPCC 2007). Subsequently, G8 leaders endorsed a 50% reduction by 2050 (IEA 2008) and the UK became the first country to legislate a reduction of 80% by 2050 from 1990 levels (HM Government 2008). Emission targets have since been legislated at the European level (European Commission 2009a) and the 2009 Copenhagen Accord (UNFCCC 2009) formalised international recognition of the 2°C threshold. However, research that year emphasised that cumulative emission is the relevant measure and that the threshold could be lower (Allen et al. 2009, Meinshausen et al. 2009, Smith et al. 2009). Scenario modelling in the Fifth Assessment Report of the IPCC (2014) concluded that, depending on the emission trajectory and other factors, a cap of 550-1,300GtCO_2 over the years 2011-2050 is required for a temperature rise of below 2°C to be *likely* and a rise of below 1.5°C to be *more unlikely than likely*. Including historical emissions, 20-40% of the 2001-2050 carbon budget was used up in the first decade.

1.2 Energy demand reduction and greenhouse gas abatement

As about 80% of GhG emissions in the UK result from fossil fuel combustion (DECC 2014g) the challenge of reaching GhG emission targets, like the challenge of energy security, must involve a transition in the use of energy. Much of the UK energy system involves the transformation of energy forms before they are demanded by the final user. Final energy demand may be split into sectors such as industry, transport, domestic, and services (DECC 2013a), while the energy transformation, or supply, system includes the large scale production of electricity and heat. Depending on the scope of analysis, fuel manufacturing sectors such as petroleum refining may be allocated either to energy transformation or industry.

In meeting the twin challenges of climate change mitigation and energy security, the UK Carbon Plan (HM Government 2011) set out a number of guiding principles. The first among them is to ensure cost effectiveness by using less energy and the most cost-effective technologies to drive further efficiencies. This central role for energy efficiency is echoed at the international level. Roadmap modelling by the International Energy Agency (IEA) captures the highest potential reduction in global emissions from efficiency measures, which would account for 38% of a 50% reduction over the period 2010-2050 (IEA 2010). The cost savings accrued from reducing energy demand could also outweigh additional costs by 2.5:1 and, after discounting future savings to present money with a 10% discount rate, save several trillion US dollars.

The Committee on Climate Change (CCC) was established under the UK Climate Change Act (HM Government 2008) to independently advise the Government on meeting emissions targets and to monitor progress. Progress towards the 80% target in 2050 is measured against a series of five year 'carbon budgets' designed to limit cumulative emissions over the period. Budgets to 2032 have so far been agreed and are on course to limit emissions by at least the amount a linear reduction path from 1990 to 2050 would yield[1]. Thus the legislation requires at least a 40% reduction in cumulative emissions over the period. Including historical emissions (DECC 2014g), this equates to a budget of nearly 28GtCO_2e over the years 1991-2050 and 14GtCO_2e over the years 2011-2050, or 1.5% of the average global budget recommended by the IPCC. Over the years 1991-2010, the UK contribution to global emissions was 1.63% (European Commission 2014c).

1.3 The industrial sector

The industrial sector is a major source of energy demand and GhG emissions in the UK. In 2010 it demanded around 2,000PJ of primary energy representing over a fifth of total UK demand, which was nearly 9,500PJ (DECC 2013a). Direct and indirect industrial GhG emissions totalled around 130MtCO_2e that year, or a fifth of the UK total of 600MtCO_2e (DECC 2014g). In terms of energy- and process-related emissions[2], industry accounted for a quarter of the UK total. The UK Carbon Plan indicates that a reduction of up to 70% in GhG emissions from the sector could be a required contribution to the legislated national target. Industrial emissions from 1990 to 2010 fell by 47% equating to a required reduction of 2010 emissions of 43%. Met under a linear reduction path from 2010, cumulative emissions would be 8GtCO_2e over the years 1991-2050 and 4GtCO_2e over the years 2011-2050, or nearly 30% of the projected carbon budget. The higher future proportion from industry than at present may be linked to a recognition of the sector's unique structural limitations and an anticipation of industrial output growth into the future (HM Government 2011).

Energy demand in UK industry has reduced and restructured considerably over the past 40 years. Most of this change occurred in the 1970s and 1980s which saw large structural shifts away from energy intensive sectors, e.g. steel and cement, in the wake of oil price shocks and a renovated national economic strategy. The energy crises also encouraged Government and industry to act on efficiency to accrue energy cost savings (DEn 1975). Aggregate energy intensity in industry fell at a rate of 2.7% over the period 1970-1990 and 1.7% over the period 1990-2010. The slower rate in the latter period is indicative of less dramatic structural change and fewer remaining cost-effective opportunities, or 'low hanging fruit', in energy intensive industry (Hammond and Norman 2012).

[1] For calculation see section A1 of the Appendix.

[2] This excludes methane emissions from landfill and agriculture.

Many aspects of the industrial sector relevant to energy demand and emissions reduction set it apart from the other demand sectors. Firstly, industry is structurally and technologically heterogeneous. It consists of a highly diverse collection of different products and processes, each with their own thermodynamic, technical, economic and market constraints. Existing within and between its subsectors are unique sets of institutional, financial, and behavioural drivers and barriers pertinent to effective technological change. This arrangement is less conducive to a 'one size fits all' approach to achieving emissions reduction; rather, it necessitates tailored solutions on a sector-by-sector basis (Dyer et al. 2008). Secondly, major parts of industry are significantly constrained by the thermodynamic requirements of their processes. About 10% of industrial GhG emissions are liberated from process feedstock and some processes are restricted to the use of high carbon fuels. This precludes significant parts of industry from the near zero emissions targets envisaged for the transport and domestic sectors by 2050 (HM Government 2011). Thirdly, industry is not confined to a single country. Most industries operate in international markets and, if subject to national or regional environmental policies that unilaterally impose high emission costs, could relocate to countries with lower restrictions. This phenomenon is known as 'carbon leakage' and though there is as yet no evidence for it (ECORYS 2013), it could occur if future emission costs are high enough (Carbon Trust 2010).

1.4 Radical technological change and innovation

It is self-evident that such a radical scale of emissions reduction by 2050 should require a radical measure of change at the emissions source. For most parts of energy intensive industry, GhG emissions are inherently a part of the industrial process. For the production cement, CO_2 is liberated from the decomposition of limestone. For the production of steel, carbon from coal is required to reduce iron ore. For the production plastic, ethylene and propylene are cracked from fossil fuels producing fuel grade by-products. These industrial processes also run at high temperatures necessitating large thermal energy inputs. The high cost of energy in these sectors has driven significant efficiency investments over time and fewer opportunities remain through improvements to existing methods.

There are three options for achieving significant emissions reduction from these processes:

1. Radical process change: this entails a substitution of the incumbent process with another process route to the same product, or with the process of a different product fulfilling the same service.
2. Carbon sequestration: this enables the incumbent process to be maintained while capturing emissions and storing them.
3. Material efficiency improvement: this covers a range of options for reducing process output within the wider industrial system, while maintaining the same output of service.

Examples include product recycling and reuse, product longevity, and dematerialisation (Allwood et al. 2011).

There are overlaps between these categories. For example, recycling of steel also entails a radical change of process and the uptake of CCS could in some cases entail substantial process change.

The concept of technological change has been well developed in innovation literature (Dosi 1988, Freeman and Perez 1988, Kemp 1994, Nelson and Winter 1977). The extent to which technological change occurs may be characterised by the dichotomy of radical and incremental, or revolutionary and evolutionary. The difference is understood through the concept of the 'technological paradigm' (Dosi 1988), which defines the artefact and prescribed set of heuristics associated with its development. The dynamics of continuous, or incremental, change is bound by the 'technological trajectory' which is the normal direction of progress set by the technological paradigm. This is distinguished from discontinuous, or radical, change which is associated with the emergence of a new paradigm. With regard to industrial processes, de Beer (2000) qualitatively defines three degrees of technical change. These are summarised here:

1. Evolutionary change: a logical continuation of the existing process improvement trend; a slight improvement in performance; no effects on key process parameters, the quality or nature of the product, or the supply chain; only small effects on the industrial organisation and technology implementation. For example, the instalment of gas recovery equipment on a steelmaking furnace.
2. Major change: the application of a new principle in the performance, at least in part, of the industrial process; a leap forward in performance; significant effect on key process parameters; small effects on the quality or nature of the product, or the supply chain; significant adaptions to the process with main components replaced though, in the case of retrofit, not necessary to build a new plant; significant potential effects on the industrial organisation and technology implementation. For example, the replacement of an open hearth steelmaking furnace with a basic oxygen steelmaking furnace.
3. Radical change: the application of an entirely new principle in the performance of the industrial process; a leap forward in performance; significant changes in the quality or nature of the product, or a new product; considerable changes to key process parameters; significant supply chain effects; new production plant; considerable effects on the implementation of technology and the industrial organisation. For example, the production of steel from iron ore via a blast furnace and basic oxygen furnace to production from scrap via an electric arc furnace.

de Beer (2000) separates technical change from the technology's stage of development, which is determined by its position on the innovation chain. In practice the development of a technology from concept to commercialisation may be iterative and non-linear. However, the model is

generally recognised as consisting of the following sequence of phases (IEA 2008): basic research, (applied) research and development, demonstration, deployment, commercialisation (or diffusion).

1.5 Policy context

In order to bring about emissions reduction in an economy, governing bodies need to design and implement policies that minimise barriers and maximise drivers to change. Policies may be characterised as 'technical push' if they support the progression of a technology through the first few phases of the innovation chain, or 'market pull' if they support progression over the last few phases. The two most overlap during the demonstration and deployment phases. Key policies that directly affect UK energy intensive industry are summarised here:

- European Union Emissions Trading System (EUETS): the EUETS is a cap-and-trade mechanism for incentivising cost-effective emissions reduction within the EU (European Commission 2014b). A limit (cap) on GhG emissions from installations in the industrial and power sectors is set by a fixed number of emission allowances allocated for a specific trading period. One allowance equals the emission of one tonne of carbon dioxide or, in some sectors, the emission of one tonne of carbon dioxide equivalent (CO_2e) in nitrous oxide or perfluorocarbons. A company's emissions must be monitored and if not met by allowances the company receives a financial penalty. Well performing companies may wish to sell surplus allowances and underperforming companies may wish to buy them. Surplus allowances can also be banked for use in consecutive trading periods. As the overall cap on allowance allocation declines the system should, in theory, incentivise cost-efficient abatement investments across the region.
- Climate Change Levy (CCL) and Climate Change Agreements (CCAs): the CCL is a tax charged on energy-related CO_2 emissions from energy intensive UK industry (DECC 2014l). Sectors may earn relief from this tax through CCAs, which are voluntary agreements to meet near-term energy efficiency and emission reduction targets.
- Renewable Heat Incentive (RHI): the RHI is a subsidy scheme for incentivising the use of biofuels, solar, geothermal, and efficient combined heat and power (CHP) or heat pump systems for the generation of heat (DECC 2014j).

Energy intensive industry is also indirectly affected by policies that influence the price of electricity including EUETS coverage of the power sector, the Renewables Obligation, Feed-in-Tariffs, the Carbon Price Floor, and others (Haydock and Napp 2013). Altogether, policies are underpinned by the need to meet regulatory targets set out at the national and European level, e.g. the Climate Change Act (HM Government 2008) and EU Energy Efficiency Directive (European Commission 2012a), respectively.

Much of industry has its own specialist research and technical expertise, access to technology, and the means for financing innovation. So the presence of clear, predictable, long-term economic incentives for technological change is vital (IEA 2009c). While regulatory and market-based policy plays a role in this regard (market pull), these should also be complemented by more direct innovation support mechanisms over the early and middle phases of the innovation process (technology push). The Low Carbon Innovation Co-ordination Group (LCICG) brings together a number of public and publically backed bodies[3] that support research, development, and demonstration (RD&D), and commercialisation of emissions reducing technologies in the UK (DECC 2013d). As far as industry is covered, it was observed by Griffin et al. (2012) that the sector had benefitted in the past from a more cohesive model for promoting RD&D, specifically energy efficiency, with strong industrial engagement and clearly set targets at the subsector level (see section A9 of the Appendix). Recently, the Department of Energy and Climate Change (DECC) and Department for Business, Innovation and Skills (BIS) launched the 'Industrial 2050 Carbon Reduction and Energy Efficiency Roadmaps Project', which has had high stakeholder engagement from eight priority subsectors of industry (DECC 2013d). However, whereas past schemes benefitted from objectivity of information and the continual oversight of an independent management organisation (Griffin et al. 2012), the present project appears vulnerable to asymmetric information regarding the true scope and potential of measures.

The LCICG (2012) recently produced a 'Technology Innovation Needs Assessment' (TINA) for industry. Key subsectors were identified based on emissions abatement potential, business creation, and the need for domestic support. The need for support was assessed by the presence of specific market failures and the opportunity to rely on innovation from outside of the UK. There generally exists significant transferable international activity, e.g. in the iron and steel sector, though less so in sectors where the UK has a strong R&D base and history of innovation, e.g. chemicals, or in sectors with country specific requirements, i.e. food and drink. Where UK industry can rely on innovation occurring elsewhere it does so at the risk of becoming less competitive. Learning-by-doing effects can also be transferred to industry through the support of cross-cutting technologies in other areas, e.g. the CCS commercialisation programme in the power sector. Notwithstanding this, targeted public sector investment is required across industry to leverage private investment and advance technology development and adoption.

It has been asserted in UK public policy reviews that governments often expect commercial actors to step in after a technology has been proven in principle, leaving public funds to be prioritised for more basic R&D (Future Energy Solutions 2005, Watson 2009). Subsequent development

[3] These include, *inter alia*, the Department for Business, Innovation and Skills, the Department of Energy and Climate Change, the Carbon Trust, the Technology Strategy Board, the Energy Technologies Institute, and the Engineering and Physical Sciences Research Council.

towards commercialisation may then stall in what is known as the 'Valley of Death', where cash flow is removed and neither public nor private actors perceive investment to technology diffusion as being within their remit (Murphy and Edwards 2003). Any future government policy in this area should ensure joined-up policy across the innovation chain and heed lessons from past UK policy (Griffin et al. 2012, Mallaburn and Eyre 2013).

1.6 Research context

In 2011 the UK Energy Research Centre (UKERC) identified the need for a better quality and coverage of data on the UK industrial sector. Of particular note was the absence of a dedicated publically available 'bottom-up' model of industrial energy demand and GhG emissions. The ENUSIM model developed by Ricardo-AEA provides analysis support for Government commissioned reports (CCC 2014, HM Government 2011, Hodges and Hawkes 2010) but is not transparent in its data, characterisation of specific technologies, or account for uncertainty. The DECC pathways calculator model takes a top-down, econometric approach unsuited to the structural and technological dynamics of the industrial sector. Against this background, the 'Usable Energy Database' (UED) project was launched to begin the process of producing an open-source database of industrial energy demand and emissions from which verifiably credible bottom-up models could be built. The database would also contribute to updating the UK MARKAL model to UK TIMES, which integrates the supply and demand sides of the UK energy system. The beta version of the UED database may be accessed online (UKERC 2013). The author was responsible for the baselines of iron and steel, cement and chemicals, all of which are updated through the present work.

The bottom-up nature of the UED project reflects a wider trend in the development and use of bottom-up technology roadmaps for informing industrial energy and climate change policy. At the global and European level, technology roadmaps have been constructed for all major energy intensive sectors: iron and steel, aluminium, cement, chemicals, pulp and paper, ceramics, and glass (CEPI 2011, Cerame-Unie 2012, EAA 2012, EUROFER 2013, Glass for Europe 2012, IEA 2013). At the national level, only very basic assessments for cement and glass have yet been undertaken (British Glass 2014, MPA 2013a). Roadmaps are invariably designed by, or in partnership with, the respective trade associations of the industries concerned. This is unsurprising as bottom-up analyses are data-rich, built on sensitive information at the process level, and require a certain degree of technical knowledge. Accordingly, the data and workings underlying these assessments are undisclosed. It is therefore not possible to confirm validity or impartiality in their conclusions. To the author's knowledge, no recent attempt has been made in the UK to openly conduct this type of assessment independent of industrial influence.

The last independent and transparent bottom-up technology projection assessment conducted for UK industry was in the 1980s by the Energy Technology Support Unit (ETSU) for the then

Department of Energy (Langley 1984a, 1984b). The study benefitted from a wide-reaching public programme to identify opportunities for energy efficiency and RD&D support. This included the 'Industrial Energy Thrift Scheme, which involved 2000 site visits, and the Energy Audit Scheme, which produced 17 detailed sector reports using formalised process energy analysis techniques based on gathered primary data. These reports were published under the 'Energy Audit Series' of the Department of Energy's Energy Efficiency Office (Hale et al. 1979). The schemes also contributed to a wider package of measures including the 'Energy Efficiency Demonstration Scheme', which sought to advance efficiency technology development and diffusion whilst addressing the UK's poor record compared with other developed countries at applying in industry the results of R&D (Future Energy Solutions 2005, Griffin et al. 2012).

1.7 Aim and objectives

The aim set out for this thesis is to **measure long-term potential to reduce energy demand and greenhouse gas emissions in UK energy intensive industry from radical change using thermodynamic and economic analysis techniques**.

The scope of this aim is bound by a number of conditions. The definition of 'long-term' is meant to coincide with long-term policy objectives and is therefore limited to 2050. The word 'potential' may include potential in thermodynamic, technical, economic, or market terms, with each measure determining the type of analysis used. The scope of 'industry' and 'energy intensive industry' is variable and should be clearly defined. The scope of energy demand and greenhouse gas emission measurement should also be made explicit and be relatable to policy and the wider economy.

As can be deduced from the aim, the present work focuses on the potential of radical solutions. This is taken to mean radical process change (see section 1.4). However there is scope for measuring the impact of other approaches insofar as they provide a basis for comparison. Regarding material efficiency as an approach, however, as this measure encompasses wider aspects of the industrial supply chain, a comprehensive assessment of its impact is considered outside the remit of the present work. The UK INDEMAND (2014) centre and its associates are researching in this area.

The thesis aim originated under the UKERC phase II 'Energy Demand' research theme and preceded the UED project. The original aim was reinterpreted to complement the work undertaken for the UED project and *vice versa*. The database constructed for the project enabled a more detailed analysis approach to be adopted in the thesis for key areas of energy intensive industry. The thesis aim also provided a framework for demonstrating the use of the database in building a transparent bottom-up model of future industrial energy, emissions, and economics.

Based on the stated aim of the thesis, the following objectives were formulated:

1. Provide a brief policy overview relating to energy demand and emissions reduction in energy intensive UK industry and define radical change (chapter 1).
2. Overview relevant thermodynamic and economic analysis methodology (chapter 2).
3. Conduct a top-down assessment of the UK industrial sector by assessing energy supply structure and historic trends, and illustrate a link between energy statistics and bottom-up data (chapter 3).
4. Produce detailed bottom-up sector studies of the most energy intensive parts of industry, apply thermodynamic and techno-economic analysis, and construct 2050 technology roadmaps (chapters 4-6).
5. Discuss assessment results and study the combined potential of identified technologies to affect energy demand and GhG emissions in the UK industrial sector out to 2050 (chapter 7).

2 Methodology

Quantifying the potential of technology options in reducing national energy demand and emissions requires the application of thermodynamic tools. Thermodynamics is the science that underpins energy analysis methods. Energy is a thermodynamic state parameter providing objective insight into the processes responsible for the depleting of natural resources. Energy analysis translates energy to real world systems and processes so that they may be understood at various levels of the national, regional and global economy.

In this chapter an overview of analysis tools and methods employed in later chapters is made. In section 2.1, relevant background thermodynamic concepts and relationships are introduced. In section 2.2, the practical application of thermodynamics in the present work is outlined by discussing various aspects and methods of energy analysis. In section 2.3, the economic methods that will supplement the thermodynamic and energy analyses undertaken are described. In section 2.4, the broad dichotomy of top-down and bottom-up perspectives in energy analysis is summarised. In section 2.5, the chapter is summarised.

2.1 Thermodynamics

Broadly speaking, thermodynamics is the science of energy and its relationship with the properties of the physical world. Energy itself cannot be measured directly but is a concept that can be described as the ability to cause change (Cengel and Boles 2006). Energy has many forms such as thermal, mechanical, chemical, electric and nuclear. Energy may be studied at the macroscopic or microscopic level. The former relates to the overall energy of a system with respect to an external effect such as gravity. The latter relates to the structure and average behaviour of particles irrespective of those external effects. For the industrial processes modelled in this thesis, velocity and changes in elevation are insignificant, and so macroscopic kinetic and potential energies are disregarded.

In order to conduct thermodynamic analysis it is necessary to specify the thermodynamic system. A thermodynamic system is defined as a three dimensional region of space, or amount of matter, enclosed by a specified boundary that separates it from its surroundings or environment (Cengel and Boles 2006). A closed system has no transfer of mass across the system boundary whereas an open system does and is bound by a control volume. Industrial processes are generally modelled as open systems (Kotas 1985).

In thermodynamic terms a process occurs when the state of a system changes. The thermodynamic state is the condition of the system as characterised by its properties, which are independent of process history and which are defined when the system is in equilibrium (Wark

and Richards 1999). Properties may be intensive or extensive. If a system were divided into parts or subsystems then the value of an extensive property of the system is the sum of the values of that property for all subsystems, e.g. energy, mass, volume, etc. Intensive properties are independent of the size or mass of the system but have value at points within it, e.g. temperature, pressure, density, etc. If a property depends only on the current state of the system, independent of the process, then it is a state parameter, e.g. energy, pressure, temperature, etc. In contrast a process parameter depends on the process path or transition and cannot be described by the state, e.g. heat and work (ibid.).

The sum of all microscopic energy in a system is known as the internal energy (U) and may be perceived as the sum of kinetic and potential energies of molecules (Cengel and Boles 2006). Kinetic energy relates to the motion of molecules. This component of internal energy is known as *sensible* energy. Potential energy relates to the forces that bind molecules together. When bonds between the molecules break or form, a phase change takes place, e.g. from a solid to a liquid. Related to this is the component of internal energy known as *latent* energy. Sensible and latent forms of energy considered together may be referred to as *thermal* energy (ibid.). Industrial processes, e.g. fuel combustion or material manufacture, are reacting systems in which the molecules themselves undergo change. When the atomic bonds between the individual elements of a molecule break or form, this is accompanied by the component of internal energy known as *chemical* energy. Equation (2-1) shows the total energy of a thermodynamic system, ignoring macroscopic kinetic and potential energies, as the sum of thermal (U_{th}) and chemical (U_{ch}) energies[4].

$$U = U_{th} + U_{ch} \tag{2-1}$$

2.1.1 First law of thermodynamics

The first law of thermodynamics (FLT) is the law of energy conservation and states that energy can be neither created nor destroyed. It is expressed in equation (2-2).

$$\Delta U = Q - W \tag{2-2}$$

Where ΔU is the change in internal energy of the system, Q is the heat added to the system and W is the work done by the system. Heat is defined as energy transfer by virtue of a temperature difference. Work is the energy associated with force acting through a distance and comes in a myriad of forms such as electrical, shaft work, pressure-volume, and so on. These transient energy forms may be described by equations (2-3) and (2-4). Where C_p is heat capacity at constant pressure, ΔT is change in temperature, W expressed here is pressure-volume work, p is the

[4] The nuclear energy, which relates to the *strong* bonds of the atom nucleus, is not included here as it is not relevant to the industrial processes studied.

internal pressure and ΔV is change in volume. Heat capacity is the energy required to raise the temperature of a substance by one degree.

$$Q = C_p \Delta T \tag{2-3}$$

$$W = p\Delta V \tag{2-4}$$

Another important property of thermodynamics is enthalpy (H), which is an extension of internal energy and a combination property. Enthalpy is defined by equation (2-5).

$$H = U - pV \tag{2-5}$$

Assuming constant pressure and the only presence of work being pressure-volume, enthalpy is equivalent to the internal energy and FLT can be rearranged to equation (2-6)

$$\Delta H = \Delta U = Q - p\Delta V \tag{2-6}$$

Therefore for a control volume, i.e. constant volume, the enthalpy change is equivalent to the heat transfer. Enthalpy has often been described as the heat content[5] of a system (Cengel and Boles 2006). However, as many industrial processes involve such work forms as electricity and shaft work, enthalpy change of a system is more appropriately thought of here as involving both heat and work transfers.

As enthalpy is a state parameter and an extensive property of mass, there are three ways in which energy can transfer to or from an open system: heat, work and mass flow. The mass flows may also be referred to as 'energy carriers' (Hammond 2009). Based on the FLT, an industrial process energy balance can be described by equation (2-7). Where m is the mass and h is the specific enthalpy of input flows i and output flows j, and Q is the heat rejected from the system. As all other forms of work transfer are neglected in this thesis, W represents the net output of process electricity flows.

$$\sum m_i h_i = \sum m_j h_j + \sum Q - \sum W \tag{2-7}$$

From an energy balance it is possible to determine the thermodynamic efficiency. Efficiency is generically defined as the useful output of a system per required input and can be no greater than 1 (or 100%). The exact calculation of efficiency will vary depending on the subject of analysis or the distinction between outputs considered as waste and outputs considered as useful.

[5] From a strictly thermodynamic point of view no medium can contain heat because heat is transitory. That is, heat is a transferal of energy across the system boundary. If heat is transferred from a system to its surroundings then the effect is an increase in the thermal energy of the surroundings and a decrease in the thermal energy of the system. Thus, where the term heat is used in this way, e.g. heat content, this should not be taken literally.

2.1.2 Chemical enthalpy

Chemical enthalpy relates to the breaking and forming of chemical bonds during a reaction. The *enthalpy of reaction* is the difference in enthalpy of the products and the reactants of the chemical reaction at a specified state. When a fuel is burned, or oxidised, to release heat this particular reaction is known as combustion and so the term *enthalpy of combustion* describes the change in enthalpy. Because heat is released the reaction is *exothermic*, otherwise a reaction will require energy and is *endothermic*.

The enthalpy of the reactants and products themselves is represented by the property *enthalpy of formation*. The standard enthalpy of formation of a compound is the amount of enthalpy released or absorbed from the formation of its constituent elements in standard elemental form[6]. So at standard conditions (25^0C and 1 atm) the elements H_2, C, N_2 and O_2, for example, are the reference species and have zero enthalpy of formation. Szargut et al. (1988) extend this concept by instead setting to zero the molecules that exist most naturally on earth. In this context the term *enthalpy of devaluation* is used in place of enthalpy of formation. For example, limestone is deposited naturally all over the world and therefore has zero enthalpy of devaluation. Other examples include air and water vapour. The enthalpy of devaluation is a more practical concept for industrial processes, for which raw materials are extracted from the earth (ibid.). The parameter also facilitates comparison with the concept of exergy which is discussed later.

2.1.3 Calorific value

Many of the materials modelled in industrial processes are burned to release heat and so may be described as fuels. When a hydrocarbon fuel, e.g. methane (CH_4), is combusted the carbon and hydrogen parts oxidise to form carbon dioxide (CO_2) and water (H_2O) respectively. The calorific value (CV), or heating value, of a fuel is defined as the amount of heat released when it is completely combusted and the products of the reaction are returned to the state of the reactants. That is, the CV of a fuel is the absolute value of its enthalpy of combustion (Cengel and Boles 2006). The gross calorific value (GCV) or net calorific value (NCV) is chosen depending on whether the water product is defined as being in a liquid or vapour phase respectively. Therefore the GCV is the sum of the NCV and the latent enthalpy of water vaporisation. As different fuels contain different amounts of hydrogen, the difference in GCV and NCV will vary between fuels. For fossil fuels the NCV/GCV ratio is typically within the range 90-95%. GCV and NCV are also known as higher heating value (HHV) and lower heating value (LHV) respectively and can be measured experimentally with the use of a bomb calorimeter.

[6] For example, hydrogen, carbon and oxygen at standard conditions (25^0C and 1 atm) take stable forms H_2, C and O_2 respectively.

The enthalpy of devaluation of compounds of C, H, O and N is equal to their NCV. This is because the products of their combustion, CO_2, H_2O (vapour phase) and N_2, have zero enthalpy of devaluation, so reaction enthalpy change is the same as reactant enthalpy. If the H_2O product was in the liquid phase, then the energy released after balancing the products and reactants would equate to the GCV.

Hydrocarbon fuels that contain sulphur (S) have enthalpies of devaluation that are slightly higher than NCV because S has an enthalpy of devaluation of 725 MJ/kmol and an NCV of 296 MJ/kmol (Szargut 2005). However the weight fraction of sulphur in industrial fuels is typically about one per cent or less, so the difference is negligible.

2.1.4 Second law of thermodynamics

According to the second law of thermodynamics (SLT) energy processes occur with direction and energy has quality as well as quantity. Energy quality can be thought of by its level of organisation or certainty. Related to this is the concept of entropy which is a measure of microscopic disorder and the associated uncertainty about the state of energy in the system (Cengel and Boles 2006). Examples of ordered energy include macroscopic potential energy such as gravitational potential, or organised kinetic energy such as shaft work or ordered flows of matter (Kotas 1985). Conversely, internal energy of matter is disordered. The disorder of internal energy makes it less accessible as work at the macroscopic level and so its entropy indicates the unavailability of a disordered form of energy for conversion into an ordered form (ibid.).

For a reversible process entropy is conserved. A process is reversible if it can be returned to the initial state with zero net energy exchange with the surroundings (Cengel and Boles 2006). However, reversible processes are ideal processes that do not occur in nature. In real processes there always occurs some form of unavoidable inefficiency, or irreversibility. Examples include, *inter alia*: friction, mixing, chemical reactions, unrestrained expansion of a gas, heat transfer through a finite temperature difference and non-quasi-equilibrium expansion or compression (ibid.). Whatever the form, irreversibility is represented by an increase in entropy between states. The increase of entropy principle is expressed by equation (2-8), where $\Delta S_{isolated}$ is the entropy of an isolated system. Thus the entropy of an isolated system during a process always increases. Only in the hypothetical case of a reversible process does entropy remain constant.

$$\Delta S_{isolated} \geq 0 \qquad (2\text{-}8)$$

Reversible processes usefully represent the theoretical limit of process performance. For a process in which one form of work is converted to another form of work, e.g. an electric motor producing shaft work, the limit of efficiency is 100% in either direction. Conversely, for a process involving conversion between heat and work there is an asymmetry. Work has less disorder and thus can convert entirely into heat by becoming more disorganised or entropic. However, for heat to

spontaneously transform into work would violate SLT. For such a transformation there would need to be a net input of work from the surroundings. The conversion from heat to work is described by the reversible, Carnot heat engine (Cengel and Boles 2006) and is shown below by equation (2-9). The proportion of heat Q that is available as work W is limited by the Carnot efficiency η_{Carnot} which depends on the differential between the heat source temperature T and the heat sink temperature T_0.

$$W = Q \cdot \eta_{Carnot} = Q\left(1 - \frac{T_0}{T}\right) \tag{2-9}$$

The greater the temperature of the heat source, the greater its energy quality, or capacity to produce work. For example, if two Carnot heat engines A and B operate to a heat sink temperature of 298K and from heat source temperatures 500K and 1000K respectively, then A has efficiency 40% and B has efficiency 70%. The only condition in which work and heat are equivalents is when heat sink is at 0K (absolute zero). In this hypothetical state, order is achieved because all molecules of the system come to rest.

2.1.5 Exergy

The term exergy was first coined by Zoran Rant in 1956 (Szargut et al. 1988) and has been a widely adopted thermodynamic analysis tool in recent decades (Hammond 2009). The concept draws from first and second law thermodynamic constraints and so concerns energy in terms of both quantity and quality. Broadly speaking, exergy is defined as the capacity of energy to perform work with reference to a specified thermodynamic state. This 'dead state' has thermodynamic equilibrium with the natural environment.

Szargut (1988) describes exergy in the context of natural resource utilisation. Resources may be viewed as forms of matter that differ in chemical composition and state parameters from the average values occurring in nature. The values of common components should be accepted as zero so that the practical utility of naturally and industrially produced energy carriers may be evaluated. Thus exergy may be defined more specifically as (.ibid):

'…the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes, involving interaction only with the abovementioned components of nature.'

Without consideration for the usefulness of energy, comparing dissimilar processes on the grounds of energy efficiency alone becomes a comparison of 'apples and oranges' (Patterson 1996). Though energy analysis is useful in determining the quantity of wasted energy, exergy analysis will also specify where in a process energy has degraded and quantifies the quality of the various process streams flowing into the system and exiting as products or wastes (Dincer and

Rosen 2007). With reference to the actual limit of performance, the potential for improvement in the efficiency of a specific process is more accurately identifiable.

The dependence of exergy on quality as well as quantity was described by van Gool (1987) and is expressed in equation (2-10), where B is system exergy, H is system enthalpy and Θ is the thermodynamic quality:

$$B = \Theta H \tag{2-10}$$

As previously asserted in for energy, exergy transfer in an open system has three mechanisms: heat, work and mass flow. By definition work has thermodynamic quality of unity. The thermodynamic quality of heat is the Carnot efficiency and is illustrated in Figure 2-1 with process temperature differential.

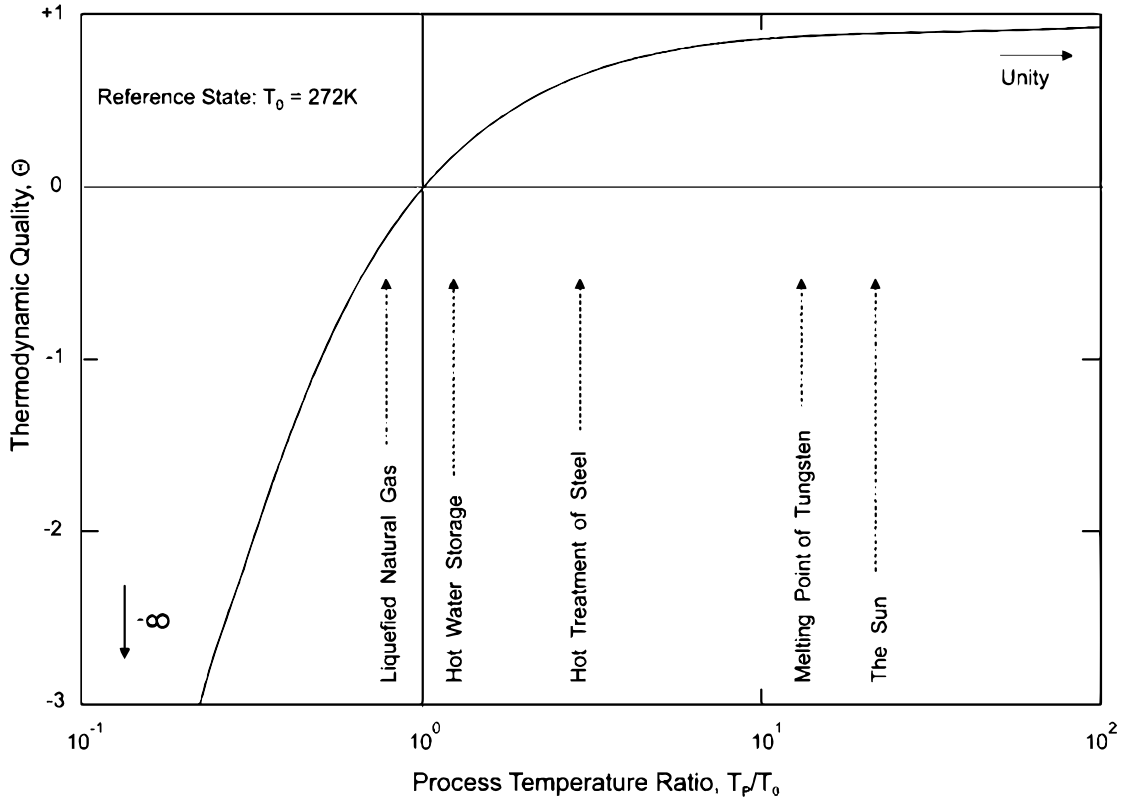

Figure 2-1: The dependence of thermodynamic quality of heat to temperature, reproduced from Hammond (2009)

Like internal energy, or enthalpy, exergy as an extensive property of mass consists of chemical and physical components. Equation (2-11) illustrates this where B_{ph} is physical exergy[7] and B_{ch} is chemical exergy.

$$B = B_{ph} + B_{ch} \tag{2-11}$$

Taking the analogue further and drawing from FLT, equation (2-12) shows that the exergy change of an open system can be balanced in a similar way to equation (2-7). Where b is the specific exergy, Q^B and W^B denote the exergy associated heat and work transfer respectively, and I represents irreversibility or exergy destruction. Note that W^B is equivalent to W in equation (2-7) because exergy is work.

$$\sum m_i b_i = \sum m_j b_j + \sum Q^B - \sum W^B + \sum I \tag{2-12}$$

Irreversibility during a process is unavoidable and is quantified by an increase in entropy between states. Irreversibility represents the lost opportunity to do work, and so is related to exergy destruction and the law of exergy loss, or the law of Gouy-Stodola (Szargut et al. 1988). This law is expressed in equation (2-13) which shows that exergy destruction[8] is proportional to entropy generation, where T_0 is the temperature of the dead state.

$$I = T_0 \sum \Delta S \geq 0 \tag{2-13}$$

2.1.5.1 Physical exergy

Physical exergy pertains to the amount of work obtainable from physical non-equilibrium with the environment involving only thermal interaction with the environment. Szargut et al. (1988) define physical exergy as:

'Physical exergy is the work obtainable by taking the substance through reversible physical processes from its initial state temperature T, pressure p, to the state determined by the temperature T_0 and pressure p_0 of the environment.'

A general expression for physical exergy is shown by equation (2-14), where S_{ph} and H_{ph} are, respectively, the entropy generation and enthalpy due to physical phenomena.

$$B_{ph} = H_{ph} - T_0 S_{ph} \tag{2-14}$$

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[7] Physical exergy is the analogue of thermal energy as previously defined, however the term 'thermal exergy' has been defined by Szargut (1988) to encompass both physical and chemical exergy. In this thesis the term thermal exergy is treated as being synonymous with physical exergy.

[8] Exergy destruction is exergy loss due to irreversibility only. As is discussed later, the term exergy loss may also be applied to the exergy of waste material output flows.

Following from this, specific physical exergy of a perfect gas having constant heat capacity may be expressed by equation (2-15), where R is the gas constant. For non-gaseous substances, where volume is constant, physical exergy may be expressed by equation (2-16), where v_m is the mean volume of the solid or liquid. For complete derivation, see Szargut et al. (1988). If initial and final states of a modelled process have equal pressure, then equation (2-17) applies.

$$b_{ph} = c_p \left[(T - T_0) - T_0 \mathrm{In} \frac{T}{T_0} \right] + RT_0 \mathrm{In} \frac{p}{p_0} \tag{2-15}$$

$$b_{ph} = c_p \left[(T - T_0) - T_0 \mathrm{In} \frac{T}{T_0} \right] + v_m (p - p_0) \tag{2-16}$$

$$b_{ph} = c_p \left[(T - T_0) - T_0 \mathrm{In} \frac{T}{T_0} \right] \tag{2-17}$$

2.1.5.2 Chemical exergy

Chemical exergy arises from chemical non-equilibrium between the substances of the system and the substances of the dead state. Szargut et al. (1988) provide the following definition:

'Chemical exergy is the work that can be obtained by taking a substance having the parameters T_0, p_0 to the state of thermodynamic equilibrium with the datum level components of the environment.'

The chemical exergy of compounds can be found in standard tables (see Table A-48 in section A5.10 of the Appendix). However, materials and fuels are in reality more complex than individual chemical compounds. For example, fossil fuels have specified ratios of elements H, C, O, N and S, but the chemical arrangement or compounds of these elements cannot be known. A method for estimating chemical exergy was developed by applying a chemical analysis of different fuel classes with different ash and moisture contents (Szargut 2005, Szargut et al. 1988). From the analysis the ratio of chemical exergy to net calorific value, β, is determined. By applying β values to the NCVs of relevant fuels, the chemical exergy can be estimated.

For fuels or materials where such information is not available, it is necessary to estimate chemical exergy from the chemical composition or mixture. This approach is demonstrated by Michaelis (1998). Equation (2-18) refers to its calculation for gas or liquid mixtures treated as having ideal gas behaviour, where x is the mole fraction of substance i. Note that the right hand side will always be negative because mixing will always be accompanied by entropy generation.

$$b_{ch} = \sum x_i b_i + RT_0 \sum x_i \mathrm{In} x_i \tag{2-18}$$

Equation (2-19) expresses the calculation for chemical exergy of liquids or solid solutions with non-ideal behaviour, where the coefficient γ accounts for the departure from ideal behaviour.

$$b_{ch} = \sum x_i b_i + RT_0 \sum x_i \ln \gamma x_i \quad (2\text{-}19)$$

With solid mixtures for which it is sufficient to assume zero binding energy between molecules, i.e. mechanical mixtures, the chemical exergy is that of the constituent parts summated. This is calculated with equation (2-20).

$$b_{ch} = \sum x_i b_i \quad (2\text{-}20)$$

2.2 Energy analysis

Energy analysis, or energy accounting as it was formerly known, emerged as a widely adopted tool in the aftermath of the 1973 oil crisis (Hammond 2004). The development of these tools was led by, *inter alia*, a number of British academics including Chapman (1974), Roberts (1978) and Slesser (1978). Central to its approach is the consideration of the first law of thermodynamics, i.e. the concept of energy balance to a system. If it requires energy to deliver some output then that energy may be counted as an extrinsic property of the output. Energy flows may then be traced through wider systems at various levels of detail.

Energy analysis is traditionally classified into statistical energy analysis, input-output analysis and process analysis (Chapman 1974, Roberts 1978, Slesser 1978). The first two rely on energy and economic statistics that are structured by disaggregation according to the standard industrial classification (SIC) system. Conversely, process analysis is a bottom-up method for which a process flow model is constructed that begins with a specified product or service.

2.2.1 Indicators

2.2.1.1 Energy efficiency and intensity

If efficiency is 'doing more with less' then quantifying it requires the definition and unit of measurement of what is done and what is less. A generic definition of efficiency is represented by equation (2-21) where more of a desired output with less of a required input increases efficiency.

$$\text{Efficiency} = \frac{\text{Desired output}}{\text{Required input}} \quad (2\text{-}21)$$

Energy analysis primarily defines energy efficiency as using less energy to produce the same amount of a desired good or service. Energy intensity is the reciprocal of energy efficiency, and so may be thought of as the energy requirement per unit of desired good or service. In either case, the output specified is a desired good or service, and the input specified is the energy required to produce it.

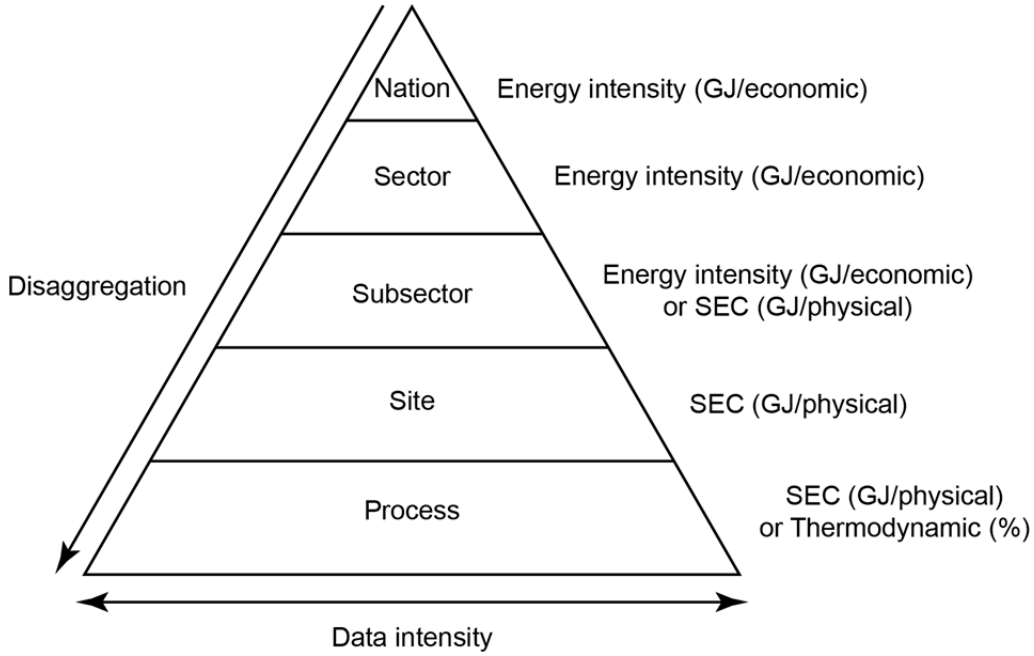

Figure 2-2: Energy efficiency indicator pyramid at different levels of economic disaggregation, adapted from McKenna (2010) and Norman (2013)

For industry the output good or service is most often quantified on either a physical basis, e.g. mass, or on the basis of economic value, e.g. gross value added. With the former, reference is made to the specific energy consumption[9] (SEC), e.g. GJ/tonne, while for the latter, reference is made to the energy intensity, e.g. GJ/£ gross value added. By contrast, the science of thermodynamics specifically assesses energy transformations and losses of a process. In which case the output specified is the energy output that is not wasted, and the efficiency is often presented as a simple ratio, e.g. %. There is no universally suitable energy analysis indicator for efficiency. However, Figure 2-2 specifies appropriate options of indicator based on the disaggregation of analysis data. The term sector may be used over the term subsector when used in the context of specific sector, e.g. industry.

As discussed by various academic sources (Farla and Blok 2001, Freeman 1997, Hammond and Norman 2010, Norman 2013, Patterson 1996), there are a number of advantages and disadvantages to each type of indicator. In order of data intensity, the indicators are summarised below.

2.2.1.1.1 Thermodynamic output

Purely thermodynamic indicators address intrinsic flows of energy, or some other related thermodynamic parameter, at the process level. This provides important measurements relating to the performance of a single process with regard to where and by how much energy is lost or

[9] The use of the term 'specific energy consumption' should be avoided in purely thermodynamic assessment as energy cannot be consumed.

degraded, which may provide insights into the location and room for improvement to a process. If significant areas for improvement are discovered, this can inform decision-making for the choice of process equipment options or the innovation of new process improvement technologies. Where there is only marginal room for improvement, this may suggest a need for substituting the process and/or the product entirely. Second law analysis in particular can give valuable insights into the opportunity for capturing waste energy and provide a fairer basis for comparison between different processes.

A key inadequacy of the thermodynamic output indicator is that it rarely represents the service for which the process was built to provide (Patterson 1996). For example, there is a market for steel but not the energy content of steel. The other key deficiency of purely thermodynamic indicators is its inapplicability to wider, interconnecting real-world systems. Focusing on single process systems limits analysis to direct inputs. Because embodied energy, donated by the wider field of energy analysis, is not physically or chemically carried by input or output flows, no useful link is made to the wider economic system. Though reference can be made to the thermodynamic conditions of the real environment through such parameters as exergy and enthalpy of devaluation, these parameters do not account for the real energy burden of the system that transforms and delivers to the process those environmental materials.

2.2.1.1.2 Physical output

Physical output has the benefit of being an objective measure of process output while directly reflecting what consumers want (Patterson 1996). As physical output, like energy input, is directly linked to the process, one can produce a robust measure of energy efficiency over time and between nations. This direct link to the process may also be a direct link between processes, which is necessary for determining the wider energy impact of a product.

When using physical output measures with energy statistics it is not possible to calculate a measure of SEC at most levels of economic sector aggregation. If the subsector of study is a homogeneous sector then a single SEC value is a reasonable representation of subsector performance. However, most subsectors defined by SIC are heterogeneous, i.e. they produce multiple and unrelated products. Where such a product mix arises there may be a number of physical measures, e.g. tonnes, litres and metres. Even when units are the same however, e.g. a tonne of steel and a tonne of cement, the aggregate output cannot be compared across time periods, subsectors, or countries if the product mix changes (Freeman 1997).

There are limitations in the availability of data for physical output indicators. PRODCOM (PROducts of the European COMmunity) (ONS 2013b) is a dataset for which a survey of product sales in physical and economic units is undertaken. However, many of the figures in the dataset are suppressed for commercial reasons. Moreover, the physical amount of product sold

over a specified time period is not the same as the amount of product produced. This is partly because of the movement of stocks which may add to or take away from the sales figure. There is also the occurrence of captive consumption in which a product may serve as a feedstock to other processes within the same company and thus require no sales transaction. This can especially be an issue for base feedstock materials such as coke or ethylene.

2.2.1.1.3 Economic output

While aiming to represent the physical output trend, economic output measures enable aggregation between products and subsectors. Two common economic measures are value of production (VP) and gross value added (GVA). Value of production is the value of shipments (sales) plus the net change to inventories (Freeman 1997). Gross value added is the value of sales less the cost of materials and services, and represents the added value of the product. Gross domestic product (GDP) is also used but more often at the national level. Though economic outputs don't relate directly to the underlying technical efficiency of economic activities, they are clearly important indicators to consumers and other economic actors.

A number of areas of inaccuracy may arise in the use of economic indicators. Value of production does not strictly represent the amount of good produced within a specified time because the production relating to some stock changes may have occurred before the time period. Further discrepancy is incurred where products may be captive consumed instead of sold. Conversely, products that are sold as feedstock to products of downstream companies may lead to double counting. Using the measure of gross value added eliminates double counting as material costs are taken away from product sales. However, gross value added makes no account of stock changes and not all cost deductions relate specifically to material inputs.

The price of any good changes over time and is affected directly and indirectly by market demand, inflation and other factors. Price fluctuations can have significant effects on economic output trends which can decouple them from physical trends and lead to potentially misleading assertions about efficiency. Price indices can be used to adjust for these fluctuations and estimate a constant price. However the measurement of a price index is itself partial to error. The main causes of error were evaluated by Freeman (1997) and are summarised here:

- Multiple prices: a myriad of different kinds of prices exist including short and long run, shipment, list, transaction and so on.
- Multiple goods: even at the most disaggregated level of SIC, subsector output is typically represented by a number of types and grades of good sold at different prices. Changes in the product mix may therefore change the aggregate price for the same physical output.

- Changes in data underlying industry price deflators: when the classification of an industry or product changes, or when the underlying methodology for calculating price index changes.
- Quality changes: when product quality increases occur over time this improvement may not be reflected in the price, e.g. personal computers.
- Shipments and material deflators: the measure of gross value added is distorted when the average price of material inputs relative to products do not change at the same rate.
- Errors in industry specialisation and coverage: the extent to which an economic measure of a good reflects the production of other goods and the degree to which measures do not reflect the entire production of a good respectively.
- Industry redefinitions: SIC revisions in which various subsectors are divided or combined at multiple levels of disaggregation.

In UK statistics, industrial output is measured by the index of production (IoP). IoP is a measure estimated from a combination of economic output adjusted for price changes and direct physical outputs weighted by economic value (ONS 2014c).

2.2.1.2 Energy demand

Measurement of efficiency or intensity alone does not explicitly address the ultimate need to reduce absolute energy or emissions. Statistical sources such as DECC and the IEA publish UK and international aggregate energy tables respectively. Key terms used in the DUKES can be seen in the appendix of their annual reports (DECC 2013a) and are summarised here:

- *Total supply*, also known as total primary energy supply (TPES), is the total supply of energy made available for the nation. It equates to the production of indigenous primary fuels (coal, oil, natural gas and biomass) and primary sources of electricity, such as nuclear, plus energy imports and minus energy exports.
- *Total demand*, or total primary energy demand (TPED), equates to TPES and is made up of all energy demands including for transformation into other energy fuels, of the transformation sectors themselves, and the final consumption of the end-use sectors.
- *Transformation* is a category of plants and industries that make available all secondary fuels and electricity for use internally or in other parts of the UK system. Included are coke ovens, blast furnaces, power producers, petroleum refineries and others.
- *Energy industry use* includes the energy used to support energy transformation, extraction and storage.

- *Final consumption* is the energy demand of the sectors and subsectors of the economy defined as 'end-use', represented primarily by the sectors of industry, residential, transport and services.

2.2.1.3 Energy measurement

The measure of energy representing a fuel, i.e. a combustible energy source, is either its NCV or GCV. There are pros and cons to using either measure, and the correct choice depends on the purpose of the analysis. GCV better represents fuel CV under laboratory conditions (AEA 2012) and gives a full account of the energy that is ultimately lost from the combustion of that fuel (Phylipsen et al. 1996). That is, the initial thermal energy transfer plus the latent energy required to vaporise the water product, which is released upon condensation. If GCV is used, then the latent enthalpy of vaporisation may be counted as a system loss and could theoretically be recovered. If NCV is used, then this energy is treated as a loss intrinsically related to the fuel and thus excluded as a potentially recoverable loss of the system.

At present, key policy drivers relate more to the environmental impact of fuel combustion, which does not concern the water product. In this case NCV may be the more appropriate measure (DTI 2005). It is also sometimes convenient to use NCV for industry as in many industrial processes water vapour leaves the system in the exhaust flue and is assumed to be unrecoverable. In which case, the maximum energy transfer from the fuel to the industrial process is closer to NCV. An exception is the use of condensing boilers in which the latent enthalpy of water vapour in the flue gas is targeted for recovery (Chen 2010). The GCV should be used in this case as it incorporates into the system an energy loss that has been reduced.

GCV is the preferred choice in UK, Canadian and US energy statistics, (DECC 2014b, EIA 2012, ONS 2013a, Phylipsen et al. 1996). However, this is inconstant with the adoption of NCV by the IEA and the statistical offices of the European Communities and United Nations (IEA 2014a). Furthermore, technical studies of industrial processes tend to adopt NCV. All of the main technological assessments and surveys across industry that were consulted for this thesis adopt NCV (Energy Audit Series 1982, IEAGHG 2008, 2013a, IISI 1998, Ren 2009).

Due to the dominance of NCV in bottom-up technological assessment literature, this thesis uses NCV in all detailed bottom-up studies (chapters 4-6). So as to relate with headline UK based statistics, the top-down/bottom-up assessment of chapter 3 adopts GCV. To facilitate the link between these two measures, conversion factors for fuels are referred to in the Appendix *pro re nata* and NCV is quoted alongside GCV for key outputs of the assessment in chapter 3.

2.2.1.4 Energy representation

In the DUKES, energy demand is represented on an 'energy supply basis' and a 'primary fuel input basis' (DECC 2014b). On an energy supply basis, energy demand is the energy supplied directly to the user after all upstream losses and conversions. On a primary fuel input basis, energy demand is the energy required by the user before all upstream losses and conversions. The approach for calculating a user's primary energy demand is to trace its direct energy supply upstream as far as its extraction from the environment.

The primary energy required by final users may be calculated by allocating to them the related transformation losses, distribution losses and energy sector demands. The primary energy demand of each of the main demand sectors (industry, transport, domestic and services) is estimated in the annual 'Energy Consumption in the UK' (ECUK) publications and reported in the DUKES (DECC 2014a, 2014b) and calculated in further detail in chapter 3 using the methodology of Chapman et al. (1974).

The energy flows in the DUKES are described as energy commodities to which the simple division of primary and secondary is applied (DECC 2014b). Primary energy commodities are drawn from natural reserves and renewable sources while the secondary energy commodities are produced from the primary energy commodities. For example, crude oil and coal are primary commodities that are transformed into the secondary commodities of petroleum products and coke respectively. In reality there are numerous levels of transformation and feedback loops that characterise the energy system.

2.2.1.5 Greenhouse gas emissions

A greenhouse gas (GhG) may be defined as a gas with global warming potential. In accordance with Articles 4 and 12 of the 1992 United Nations Framework on Climate Change (UNFCCC), GhG refers to a basket of six greenhouse gasses including carbon dioxide, methane, nitrous oxide and others (UNFCCC 2014). The bulk of greenhouse gas emission is CO_2 and thus GhG is measured by mass of CO_2 equivalent (CO_2e). A CO_2 or GhG emission factor (EF) is often applied to energy, e.g. $kgCO_2/GJ$ (GCV), so that they may be used readily with energy statistics to calculate energy-related emissions. More generally, GhGs may be described as the by-products of chemical reactions. Significant emissions also arise from non-combustion reactions associated with industrial material processing. For example, in cement manufacture limestone is decomposed liberating vast amounts of CO_2 ($44kgCO_2$/tonne limestone), which make up two thirds of the total CO_2 emission from the sector (MPA 2013b). As such, a more appropriate way to assess emissions is with mass related EF units, e.g. $kgCO_2$/tonne, applied to all mass flows of fuel and non-fuel flows.

2.2.1.6 Production-based and consumption-based indicators

Underpinning any type of resource or emissions assessment at any level of an economy is the dichotomy of production and consumption. The distinction has vital conceptual, practical and political connotations. Researchers at the University of Leeds have estimated consumption-based emissions for the UK Government using an environmentally extended multi-region input-output model (EE-MRIO) (House of Commons 2012). If an indicator is production based, only direct inputs and outputs are counted. For example, total energy demand or supply in the UK (as published by the DUKES) is production-based as it equates to indigenous production of energy along with direct energy imports and exports (DECC 2013a). For it to be consumption-based, the energy embodied in trade would also have to be included.

2.2.2 System and level

In order to fully describe what is being covered by an energy analysis two elements are distinguished here: system and level. These elements are defined here as follows:

- System: an arbitrary specification defining the subject of analysis, e.g. the global cement industry, the UK steelmaking process, China. The choice of system is influenced by the method of energy analysis.
- Level: the level of regression is the degree of indirectness an input can have on the system, e.g. a first level analysis to a basic oxygen furnace (the system) may include the thermal energy carried by the input of hot molten iron and a second level analysis will include the direct energy inputs to the blast furnace that produced the iron, and so on.

Choosing the system depends on the goal of the analysis and may be defined by a number of conditions. In statistical energy analysis a system is typically defined by geography as well as an economic, or SIC, sector. A sector, as defined by SIC, may be viewed as a collection of physically isolated activities grouped together by some economic association. Conversely, a process analysis view describes a sector by its process, which is made up of sub-processes linked by real material flows. For example, the UK iron and steel sector described by SIC is not the same as the UK steelmaking process. The former is the aggregation of all process plant activity or any other activity classified as an activity of the sector. The latter defines each key sub-process and measures only its contribution to the wider steelmaking process.

The advantage of defining a system by SIC is that it allows for a large coverage of energy demanding activities over a number of aggregation levels. The disadvantage is that it is not designed with regard to the technical process. The result might be a bundling of disparate processes or the division of real process chains. This adversely affects the validity of conclusions about the potential of technological solutions. A good example of process splitting is found in the

structure employed in the DUKES (DECC 2013a). In it the iron and steel sector excludes blast furnaces and coke ovens, both of which are integral to the steelmaking process. Indeed without blast furnaces the iron and steel subsector does not produce iron.

Once the system boundary has been specified, it is necessary to state the level of analysis. Level 1 would include only the direct energy inputs to the system. For example, a thermodynamic system is limited to this level of regression because it models the real flow of energy carried into and out of the system. At level 2 the inputs to the inputs are also included. The energy at level 2 is said to be embodied, or sequestered, by the direct inputs. Analysis levels are discussed further in relation to process analysis in section 2.2.3.3.2.

By enabling the embodiment of energy (or emissions) to the material inputs or outputs of a system, Level 2 analysis is useful for consumption-based indicators. Conversely, Level 1 analysis is suitable only for developing production-based indicators.

2.2.3 Techniques

2.2.3.1 Statistical energy analysis

Statistical energy analysis (SEA) draws from available statistics on energy. Energy statistics tables are built from data on the trading of fuels and electricity. Energy in UK statistics is calculated from fuel commodities using average GCVs. The DUKES and the Energy Accounts (EA) of the Office of National Statistics (ONS) are key datasets of UK national statistics, whereas the Iron and Steel Statistics Bureau (ISSB) is an example of statistics published at the sector-level. The availability and disaggregation of data will ultimately determine the potential of SEA, but coupled with output data one can make a cursory, top-down assessment of the average energy demand relating to products in the economy. Energy trend analyses such as decomposition analysis may also be applied to assess changes over time in more detail. For methodology on decomposition analysis conducted in this thesis refer to Ang (2005).

However, depending on the division of subsectors and their allocation to the specified output, inaccuracies in the true energy demand for that output may develop. Sectors in the DUKES and EA are categorised by the UK standard industrial classification (SIC) system which groups sectors by product categories with no regard for the production process. Overall this type of analysis is suited to the national level but may lead to significant error at or below the sectoral level. SEA forms the basis of the top-down analysis conducted in this thesis (chapter 3).

2.2.3.1.1 Decomposition analysis

The underlying method of decomposition analysis for SEA is known as Index Decomposition Analysis (IDA). This approach largely benefits from its simplicity and has been used in numerous

studies from the UK (e.g., Bending et al. 1987, DTI 1994, Howarth et al. 1991, Jenne and Cattell 1983). A more detailed background on IDA is provided by Norman (2013).

In general, the IDA method may be described by equation (2-22). Where V is the aggregate variable under examination, x is a factor influencing change in V over time, n is the number of factors, and rsd denotes the residual factor, i.e. change remaining after n factors are accounted for. The time period of analysis is from 0 to T.

$$\Delta V_{tot} = V^T - V^0 = \Delta V_{x_1} + \Delta V_{x_2} + \ldots + \Delta V_{x_n} + \Delta V_{x_{rsd}} \quad (2\text{-}22)$$

Where the aggregate variable is industrial energy demand, factors of change are output, structural change, and intensity. Output refers to the total output of industry, structural change refers to the relative outputs of constituent subsectors, and intensity refers to subsector energy demand per output. In a past UK government energy paper (DTI 1994), the output effect is sector energy demand moving pro-rata with total sector output, the structural effect is the difference between the output effect and the summation of output effects at the subsector level, and the intensity effect is the remaining energy demand. Thus, for simplification the energy intensity effect was assumed here as the residual term.

There are a number of refinements to the IDA method (Ang 2004). Developed by Ang (2005), the most scientific among them is the log mean Divisia index I (LMDI I) method. This provides perfect decomposition with no residual term. The method is described here by equations (2-22) and (2-23). Where there are i subsectors, k denotes a factor of change, and a and b denote two time units in which b precedes a by one unit.

$$\Delta V_{x_k} = L(V_i^T, V_i^0) \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \quad (2\text{-}22)$$

where:

$$L(a, b) = \frac{a - b}{\ln a - \ln b} \qquad \text{if } a = b, \text{ then } L(a,b) = a \quad (2\text{-}23)$$

2.2.3.2 Energy Input-output table analysis

Energy Input-output (I-O) table analysis originates from economic input-output table analysis (Roberts 1978). The method involves the construction of a square matrix showing the economic flows of commodity between the various subsectors (SIC) populating the rows and columns. There are drawbacks to this approach. As with SEA, data aggregation requires heterogeneous sector groupings with no meaningful measure of SEC to attribute. As the matrix is based on financial transactions errors can also arise particularly where commodities are liable to large price

fluctuations. However, energy I-O analysis provides a clear view of system flows and is sufficiently accurate at the national and international level. The method has been used for consumption-based emissions accounting in the UK (House of Commons 2012), but is not a suitable technique for the present work.

2.2.3.3 Process energy analysis

Process energy analysis, or process analysis (PA), is based on the connected flow of materials required to yield a specific product, or set of products, e.g. a steel beam, a car, or a bushel of wheat (IFIAS 1975). Broadly speaking, the analysis involves three key stages: identify the network of processes contributing to the specified product; analyse each process to identify energy, material and equipment inputs and outputs; assign energy values to the outputs contributing to the specified product. The approach has conventions defined by the International Federation of Institutes of Advanced Studies (IFIAS) and set out in detail at the first 'First Workshop of Energy Analysis' held in Guldsmedshyttan, Sweden in 1974 (IFIAS 1975).

Very few process analyses relating to the UK have been published over the past three decades (McKenna 2009). The last attempt to assess UK industry in this way was the Energy Audit Series (EAS) jointly issued by the then Department of Energy and Department of Industry. Process analyses were conducted for a number of key energy intensive industries, e.g. steel (Energy Audit Series 1982), from the late 1970s to the early 1980s to determine industrial performance and highlight areas for research, development and demonstration (RD&D) support. The 17 EAS reports contributed to a detailed study of industry published by the Department of Energy in 1984, in which industrial energy use and efficiency was projected out to 2000 (Langley 1984a, 1984b).

Conducting a PA properly is data intensive; the construction of a database is recommended as opposed to relying on statistical energy data tables. The PA requires detailed knowledge of the industrial network of interconnected process operations contributing to the system product. Defining the system boundary can also affect results if it is not clear which operations are significant, although this is less of an issue for the energy intensive industrial sectors, which are more likely to control the important energy demanding processes. PA forms a key part of the bottom-up analyses of this thesis.

The IFIAS reports provide a coherent methodology guiding on the definition of units and measures, system boundary, level of analysis, energy partitioning, graphic presentation, and so on (IFIAS 1975, Roberts 1978). These are summarised here.

2.2.3.3.1 Definition of measures

The term 'energy analysis' may encompass not only the study of energy but of enthalpy, exergy, Gibbs free energy or any other thermodynamic state parameters sequestered in the provision of a product or service. A number of energy measures are defined (IFIAS 1975):

- Process energy requirement (PER) is the sum of energies of all fuel inputs combusted to drive the processes enclosed by the system boundary.
- Gross energy requirement (GER) is the sum of energies of all fuel inputs and other inputs, for which process fuelling is not the primary function, to the processes enclosed by the system boundary (PER plus non-fuel energies).
- Net energy requirement (NER) is the sum of all energies of all fuel and non-fuel inputs to the processes enclosed by the system boundary, less the energies of process outputs.

2.2.3.3.2 Level of analysis

Depending on the nature of the process under investigation or the requirement for detail, the analyst designates a level of regression. Figure 2-3 is a simplified representation of a regression chain, where the dotted lines indicate energy flows.

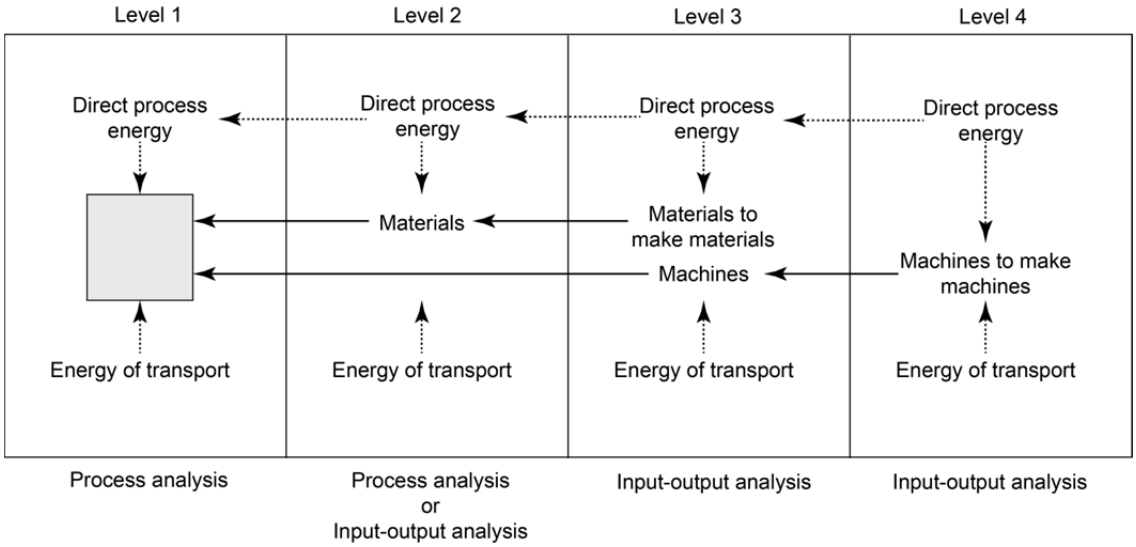

Figure 2-3: Analysis levels of a process analyses, adapted from IFIAS (1975) and Hammond (2009)

At level 1, only the direct inputs to the system, or the processes enclosed by the system boundary, are accounted for. This level covers energy inputs, such as fuels and electricity, on an energy supplied basis. Though this level can be useful from an engineering or technological perspective, it misses important factors from the wider perspective of resource depletion. At level 2, the direct energy sequestered, or embodied, in the level 1 energy inputs and other material inputs are included. The former includes, for example, the process energy demand in generating an electricity input or in refining a petroleum input. The latter includes, for example, the energy

demanded to manufacture lime in a kiln. Regression to level 2 will typically capture 90-95% of the energy demand to level 4 and so can be regarded as a reasonable representation of a product's overall energy requirement. This is especially the case in energy intensive industries as most energy demand is required at stages close to the industrial product.

In Level 3 the energy required to produce other energy forms is further regressed and the energy needed to acquire the raw material feedstock used in material manufacture is presented. In reality this feedstock could also be another manufactured material further up the production chain. However the first regression of material inputs to the industrial sectors studied is typically the raw material in the ground. Level 3 also introduces the energy required to manufacture the capital equipment required to carry out the studied system. Level 4 continues the regression for capital equipment only.

Also shown in Figure 2-3 are the analysis techniques suitable to each level. I-O analysis becomes possible only from level 2 as in this analysis it is necessary to attribute energy (or emissions) to input and output flows of products.

2.2.3.3.3 Graphical representation

The conventions applied to the graphical representation of process analyses are summarised below. The diagrams for UK steelmaking may be referred to in section A5.4 of the Appendix.

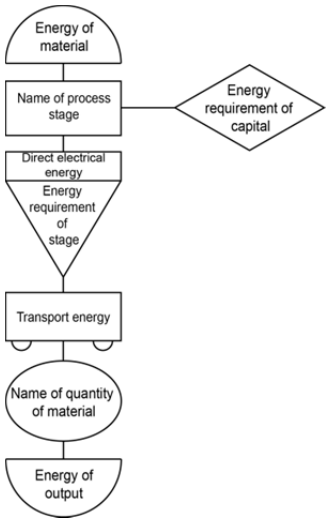

Figure 2-4: Graphical symbols of process analysis flow diagrams, adapted from IFIAS (1975)

2.2.3.4 Further thermodynamic assessment

While PA provides a basis for technological comparison as well as identifying the most energy intensive parts of an industrial process chain, it does not explicitly account for energy losses or room for improvement. Equation (2-25) follows from the thermodynamics presented in section 2.1, to determine the energy loss in an industrial process. Here energy E includes the chemical

enthalpy (enthalpy of devaluation) and thermal enthalpy of all mass flows plus work and heat transfers, where electricity is viewed as work and heat transfer losses are investigated as part of the overall loss. The sum of input energies is denoted by E_{inputs} and the sum of useful product or by-product energies is denoted by $E_{products}$. Remaining is E_{waste} which is the sum of waste output energies plus heat transfers to surroundings.

$$E_{inputs} = E_{outputs} = E_{products} + E_{wastes} \quad (2\text{-}25)$$

The analogous balance for exergy is described by equation (2-26). The additional component of the equation is $B_{destruction}$ which represents the exergy that is lost due to irreversibility. Exergy wastes and exergy destruction can be described generically as exergy loss.

$$B_{inputs} = B_{outputs} + B_{destruction} = B_{products} + B_{wastes} + B_{destruction} \quad (2\text{-}26)$$

The definition of the products of a system introduces potential for ambiguity. Many industrial processes recycle or sell various process by-products, such as process water and slags, and so care should be taken when classifying which outputs are wastes and which are products. In the absence of detailed knowledge of the use of an output, assumptions need to be made as to which category that output belongs.

Consideration should also be taken as to what part of the exergy destroyed may be avoided through changes to the process and which are inherent or intrinsic to that process. Kotas (1985) defines intrinsic exergy destruction as: '*the irreversibility rate possible within the limits imposed by physical, technological, economic or other constraints*'. The conditions for estimating this rate must be specified for the process under examination and may include: heat transfer media of different heat capacities, uncontrolled chemical reaction, economic constraints such as consideration of a minimum level of productivity, etc (ibid.). The part of exergy destruction that is not intrinsic is referred to as the avoidable irreversibility rate. Accordingly, the part of exergy loss that is not intrinsic may be described as avoidable exergy loss. The avoidable exergy loss offers an indication of processes with the greatest improvement potential (ibid.).

System losses may be further scrutinised as a relative parameter of process inputs and is the basis of determining efficiency. If all input and output flows are counted, then energy efficiency has unity. Exergy efficiency must be less than unity because of irreversibility, or destruction. This form of efficiency is referred to by Cornelissen (1997) as 'simple efficiency' and is described for exergy by Equation (2-27), where simple exergy efficiency is denoted by ψ_s.

$$\psi_s = \frac{B_{outputs}}{B_{inputs}} \leq 1 \quad (2\text{-}27)$$

When discounting from the output the energy or exergy that is wasted, exergy efficiency relates to the generic expressions for efficiency given in by Equation (2-21). This efficiency (ψ) is expressed in Equation (2-28):

$$\psi = \frac{B_{products}}{B_{inputs}} \quad (2\text{-}28)$$

In some cases a part of the exergy input flows through the system unaffected (Wall 2003). Examples include the use of high energy feedstocks making up the process product, e.g. refinement of crude oil into petroleum products or the carbonisation of coal into coke. The exergy in these flows make up the 'transit exergy' of the process and are accounted for by deducting them from the exergy inputs and products. Efficiency in this case may be described by Equation (2-29).

$$\psi = \frac{B_{products} - B_{transit}}{B_{inputs} - B_{transit}} \quad (2\text{-}29)$$

As there may be ambiguity in the distinction between process and feedstock energy, there may be ambiguity in deciding what is transitory. For example, carbonisation of coal in coke ovens does not pass on all the energy in coal to recoverable energy products. Furthermore, some of the coke product is inevitably combusted in the process (IISI 1998). In the presence of ambiguity it is useful to analyse efficiency both with and without transit energy.

2.3 Economics

A basic investment appraisal considers the capital investment of a technology along with annual costs, revenues and savings. The capital investment typically includes the installed costs and contingencies, whereas the former typically includes cost of equipment, equipment spare parts, design and engineering, construction and installation costs (IEAGHG 2008, 2013a). Annual costs are divided into fixed and variable operating costs. Fixed operating costs include maintenance and labour, whereas variable operating cost includes the cost of raw materials, fuels and other consumable inputs as well as costs relating to outputs such as disposal or quantity-based government related costs, e.g. cost of CO_2 emission. Where there are products or by-products of value these are be sold to create revenue.

When deciding on the investment of a new energy efficiency technology, the investor should estimate the discounted cash-flow of all costs and revenues over the future lifetime of the technology and compare it with a base case. The base case might be to continue business without the new technology, refurbish the existing technology, or replace the existing technology with the same technology. In reality the investor will need to compare numerous technology or technology combination options.

2.3.1 Net present value

The present value (PV) of something is related to its future value (FV) by the present value factor (PVF). This relationship is expressed by equation (2-30).

$$PV = PVF \times FV \quad (2\text{-}30)$$

The PVF can be expressed by the equation (2-31), where r is the discount and n the number of years from the present.

$$PVF = (1 + r)^{-n} \tag{2-31}$$

The net present value (NPV) is the sum of all project cash flows discounted to the present value over the life of the project (Boardman et al. 2001). With initial investment *I* and uniform annual revenue *R* (which can be negative if it is a net cost) and N years for the project, a simplified expression is shown in equation (2-32).

$$\begin{aligned} NPV &= -I + R\sum_{0}^{N}(1 + r)^{-n} \\ &= -I + R\left[\frac{1 - (1 + r)^{-N}}{r}\right] \end{aligned} \tag{2-32}$$

The discounted payback period is the time after which the discounted cash flow becomes positive and is reached when the investor breaks even on investment. For energy efficiency technologies the investor chooses an appropriate discount rate based on various factors including inflation, risk, hidden costs, uncertainty and so on. The higher the discount rate, the less economically attractive an energy efficiency project is deemed to be.

2.3.2 Marginal abatement cost curves

The marginal abatement cost (MAC) curve is defined as *'a graph that indicates the cost, associated with the last unit (the marginal cost) of emission abatement for varying amounts of emission reduction'* (Kesicki 2011). That is to say, different measures or technologies for reducing GhGs across an economy or within a specific sector can be assessed in terms of the associated extra, or marginal, costs and reduction in, or abatement of, GhGs compared with a specified baseline. The baseline is the part of the sector or economy that the option replaces and is sometimes described as business as usual (BAU). The cost associated with the technology option is the annualised cost over the lifetime of the technology and is calculated using a discounted cash flow analysis.

MAC curves derive from 'saving curves' or 'conservation supply curves' which were first developed in the wake of the 1970s oil price shocks as a way of analysing options for reducing oil consumption (Kesicki 2011). These would later be used for electricity demand and abatement of air pollutants (ibid.). MAC curves have become very popular with policymakers in recent years as they can clearly indicate how much GhG abatement a country or sector can afford and which areas should be targeted with which kinds of policies in order to maximise effectiveness of intervention (Bockel et al. 2012).

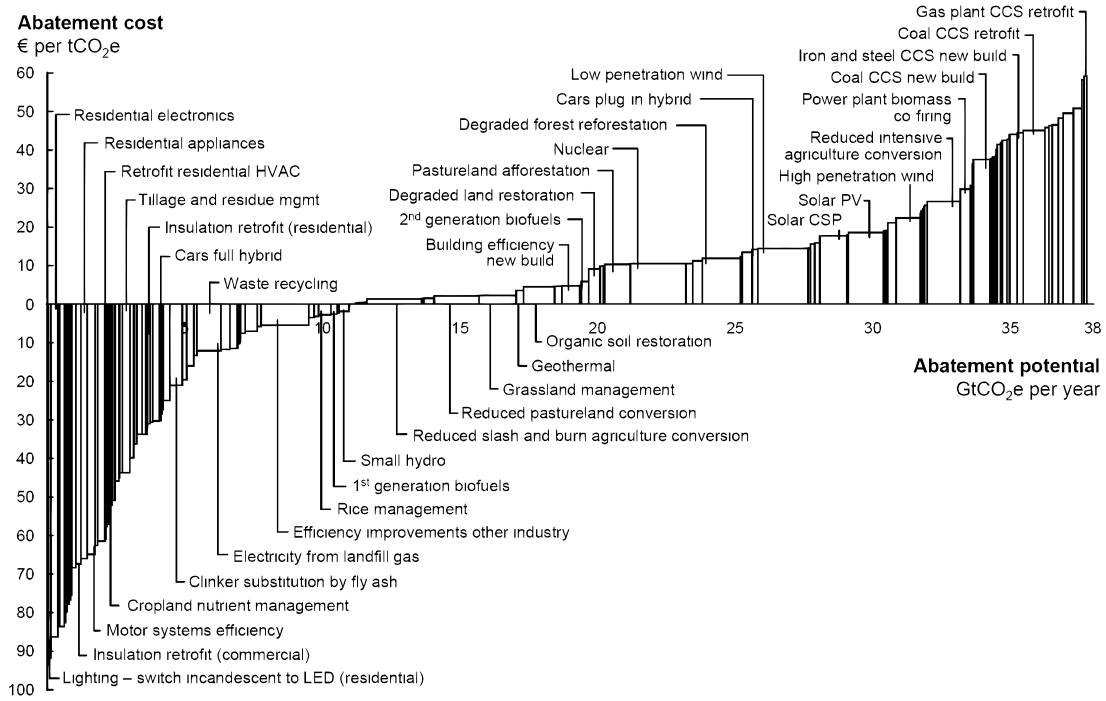

Figure 2-5: Global greenhouse gas MAC curve, adapted from McKinsey and Company (2009)

An illustrative example is shown in Figure 2-5 which is a MAC curve of global greenhouse gas abatement options across multiple sectors in 2030 (McKinsey and Company 2009). Each bar represents an emissions abatement option. Bar width is the abatement associated with the option against its baseline and bar height is the annualised cost per unit of abatement relative to its baseline. The total width of all bars is the total abatement potential of the pathway while the total area of the bars is the overall marginal cost of the pathway.

Despite their clarity of presentation and popularity amongst policymakers, MAC curves can have numerous weaknesses (Kesicki 2011). Firstly, the assumptions used in calculating the baseline, technology abatements and costs are often not stated. So as not to invalidate itself as a tool for informing policy decisions, a MAC curve should be published alongside workings and consideration of uncertainty. Secondly, the MAC curve displays costs for a snapshot in time and so cannot capture differences between pathways that are subject to intertemporal dynamics. The technologies shown would in reality be deployed at different times and over different, potentially overlapping, time periods. Thirdly, a MAC curve cannot incorporate path dependency. For example, a technology that is 'locked-in' at lower costs but replaced at higher costs.

MAC curves have been used in a number of studies assessing abatement options across multiple industrial sectors (Element Energy 2010b, Hodges and Hawkes 2010, IEA 2009c). For specific industrial sectors there may only a few long-term options available within a given pathway such that MAC curves become less useful. In which case, the curve's structure may be employed to visualise a comparison between alternatives, as opposed to assessing a portfolio of additive options. For the present work these are referred as comparative abatement cost (AC) curves.

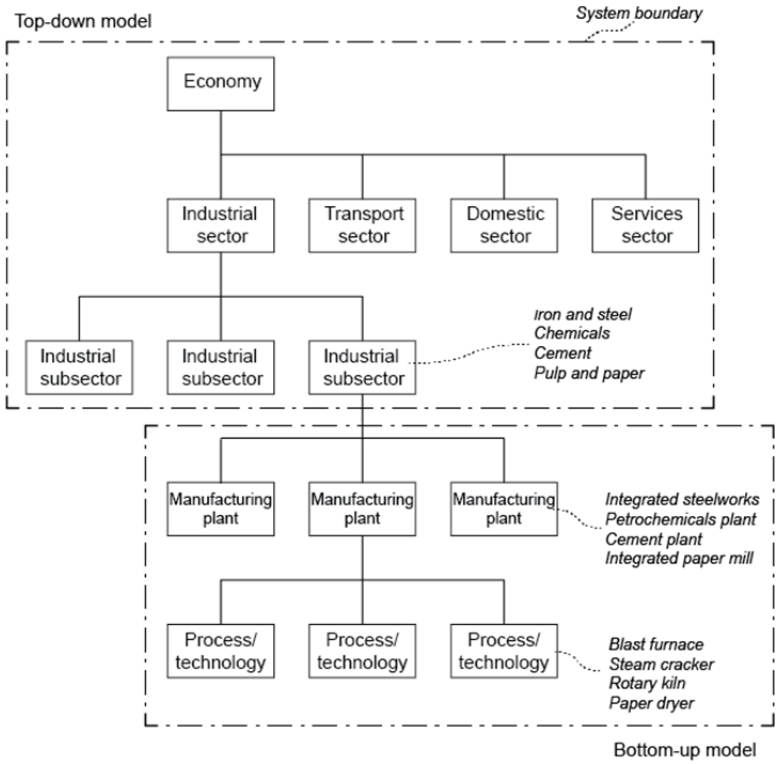

Figure 2-6: Schematic illustrating the top-down and bottom-up model relating to economic structure, adapted from Dyer et al. (2007)

2.4 Top-down and bottom-up characterisation

Broadly speaking, energy analysis may be classified as either top-down or bottom-up. Figure 2-6 illustrates what is meant by top-down and bottom-up relating to coverage of the various structural levels of an economy. Top-down analysis is based on energy, emissions, and economic statistics structured according to SIC and applying to value-based output indicators. Data is sourced from national or international datasets spanning all economic sectors, e.g. the DUKES. Suitable analysis techniques include SEA and I-O tables. Bottom-up analysis is based on detailed data relating to the manufacturing plant or process. Data is sourced from individual companies or representative subsector trade and statistical bodies. PA and thermodynamic analysis tools are suitable at the bottom-up level. SEA is only suitable provided the data is still plant-level and output is physical. Techno-economic appraisal is also possible if analysis distinguishes to the level of individual process plant and equipment technologies.

Top-down studies enable a wider coverage of activities and depend on publically available industry-wide datasets. However, the aggregation of data limits the analyst to drawing indicative and generalised conclusions about sectoral groupings or industry as a whole. Conversely, bottom-up studies inform for technical and thermodynamic improvement potential, and can model the economics entailed in overcoming inefficiency or abating emissions. Process specific input and physical output data also bring much greater certainty to historical trend or forecasting assessment. The limitation of bottom-up studies is their decentralised and incomplete coverage of

national resource demand, and the relative difficulty in obtaining data. The approach taken in the present work is to conduct bottom-up analysis of key energy intensive sectors and place them in the context of top-down statistics. This is down by soft-linking the bottom-up sectors with statistics. In doing so the sectors are implanted into top-down category of industry. Any energy and emissions remaining between the two is labelled 'other industry'.

2.5 The bottom-up approach

The diverse technological structure of industry makes it necessary to take a sector-by-sector approach. The nature of a bottom-up study for any one sector of industry will vary depending on the detail of the study. The study's detail will depend on the availability of time and data. Limitation on time will require sectors to be prioritised according to their importance with regard to greenhouse gas abatement and energy demand reduction. The availability of good quality data influences the range of analysis techniques available and the number of assumptions underpinning the bottom-up model.

The UED project prioritised six industrial sectors for study based on: relative size and intensity of GhG emission and energy, structural homogeneity, historical trends, and data availability. This thesis gives priority to the sectors of: iron and steel, cement, and chemicals. Iron and steel is the largest energy demanding and GhG emitting UK industrial sector that is homogenous in structure. Chemicals is slightly larger from an energy and emissions standpoint, but being heterogeneous it is more aptly described as a collection of sectors. Iron and steel also has a much better data coverage of processes because the processes are few and change less often. Furthermore, the data is more widely available owing to a lower intensity of private R&D, and the wider presence of comprehensive statistical bodies such as the ISSB and World Steel Association. The cement sector is smaller but usefully homogenous and has good quality UK data collected by the Mineral Products Association (MPA) and under the Cement Sustainability Initiative of the World Business Council for Sustainable Development.

Despite the differences highlighted between these sectors, it is useful to outline a generic framework to the bottom-up approach. Figure 2-7 illustrates the approach taken for the bottom-up studies of this thesis. Shown is the chain of objectives characterising the study and the tasks that each objective can entail. As the purpose is to model industrial sectors for their long-term abatement and energy reduction potential, it is important to understand as fully as possible the way in which a sector changes over time. Hence the approach may be characterised by an account of the sector's past, present, and future. The tabulation of present process energy and material flows accompanied by techno-economic information was the basis of the UED project. The diagram therefore illustrates the contribution of this project to the approach. The most important addition to the previous work will be the incorporation of techno-economic roadmap projection

modelling. Such models will provide the flexibility to maximise the scope for futures investigation by enabling for variables to be tested and for numerous roadmaps to be designed and optimised.

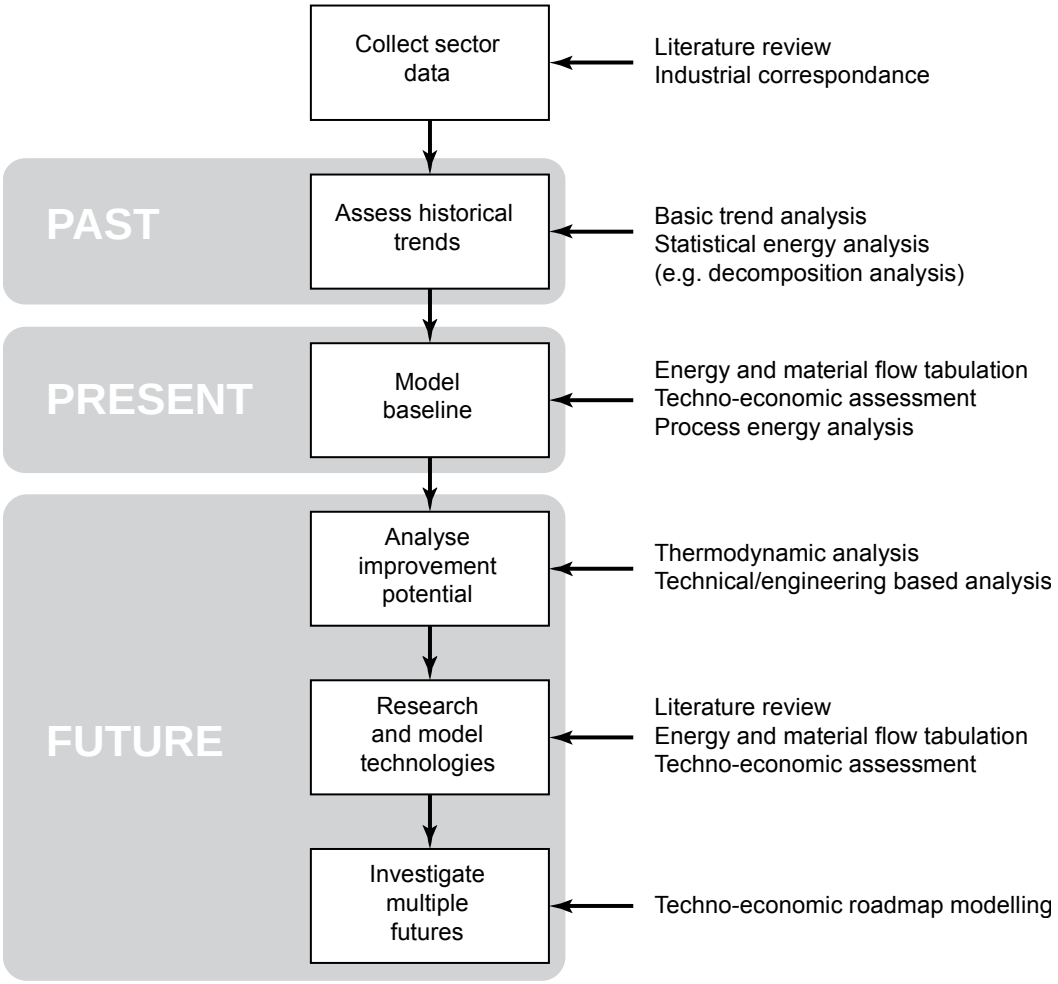

Figure 2-7: Methodological process representation of the bottom-up approach

2.6 Summary

Thermodynamics lends scientifically robust properties that are independent of the thermodynamic process path and characterise the state of the system. Since energy is a state parameter and the ability to affect change, it is a usefully objective measure to assess the performance of industrial processes and systems.

Purely thermodynamic analysis may be conducted to examine the waste and degradation of energy as it is transformed and transferred by an industrial process. Balancing mass flow enthalpies and transfers of work and heat through open systems forms the basis for determining industrial thermodynamic efficiency in terms of energy quantity. Applying the concept of exergy provides greater scrutiny to the efficiency of the process by revealing the quality of energy flows and limit for improvement.

The parameters and principles of thermodynamics may be further exploited with the use of energy analysis methods. A more generic concept of energy efficiency is introduced to consider the use of energy for the sake of some specified output. Then it is possible to build aggregated or connected systems to model patterns of energy use over industrial sectors, nations and beyond. Applying energy analysis enables a measure of the impact of deploying technologies in the specified system. This may be assessed over time periods most effectively with the use of physical output indicators. However, economic output indicators can be utilised to provide more indicative insights from the top-down perspective.

For any type of energy analysis it is essential to define the system, or system boundary, and level of analysis. The system is an arbitrary specification defining the subject of analysis whereas the level is degree of regression for system flows. The system may be defined from a bottom-up view, in which case it is a process flow that links to a specified product or service output. Alternatively the system is defined by a top-down view and is better described as a group of individual activities. The PA method is more applicable to the bottom-up perspective while SEA and I-O table analysis are more applicable to the top-down view. Consideration of analysis level should be made depending on whether indirect, or embodied, impacts are to be accounted for. Regressing up the levels of analysis accounts for the wider impact of a system and thus provides for a fairer comparison between systems. It is also conceptually aligned with the idea of consumption and the use of consumption-based accounting methods.

A procedure was outlined for the bottom-up approach given to sectors studies in later chapters. The method emphasised the need to account for past, present, and future, and indicated where previous work has contributed. It was highlighted that the most appropriate way to investigate bottom-up energy and carbon futures is to develop a flexible techno-economic roadmap projection model.

3 Top-down analysis and linking

In this chapter a top-down/bottom-up assessment of energy demand and GhG emissions from the UK industrial sector is undertaken. The main purpose of the assessment is to build a framework through which bottom-up sector studies can be linked to the level of UK-wide statistics. In doing so key structural features and historical trends of the industrial sector are also examined and baselines are established. In addition, areas of weakness in the validity or usefulness of available statistics are examined.

In section 3.1, statistical data sources are reviewed and contrasted. In section 3.2, top-down scopes for energy and emissions are defined. In section 3.3, key sectors of industry are analysed and compared to form a bottom-up structure. In section 3.4, a top-down/bottom-up framework is established to provide context for bottom-up analysis in later chapters. In section 3.5, an examination of historical trends is made. In section 3.6, some observations from the chapter's analyses are discussed. In section 3.7, the chapter is summarised and concluded.

3.1 Energy and GhG emissions data

Underpinning top-down and bottom-up analyses are different sources of data at different levels of scope and disaggregation. While top-down analyses rely on national or international statistical databases split by economic category, bottom-up analyses require process- and plant-level data. Installation-level, or site-level, data sits between these two data levels and analysis undertaken with such data has been described as meso-level (McKenna 2009). UK data for each level of analysis is reviewed here.

3.1.1 Statistical databases

The prime source of national energy statistics for the UK is the Digest of UK Energy Statistics (DUKES), which has been published annually by the Government since 1950 (DECC 2009). The data collected is based on the receipts of energy suppliers and consultation between DECC and industrial bodies, e.g. Iron and Steel Statistics Bureau (ISSB). The data presents the production and demand totals of fuels and electricity but until recently made no account of the energy transformation system by which a primary resource, e.g. natural gas, is converted to a secondary form, e.g. electricity, for final energy demand. In 1999, aggregate energy balances were introduced to bring structure and translate primary energy totals to final energy users. These users, or sectors, are generally disaggregated to the 2-digit level of the SIC system.

Further disaggregation of sectors is provided by the annual Energy Consumption in the UK (ECUK) publication. The ECUK is a secondary analysis which incorporates data from other sources into the headline figures published in the DUKES. Regarding the industrial sector,

disaggregation to the 4-digit SIC level was accomplished for the period 1990-2007 by using data from the ONS purchases inquiry (PI) and constraining it to broader DUKES totals. This method, however, provides limited accuracy and has not been corrected for boundary changes over time. Nevertheless, the PI ceased in 2006 and will not be reinstated until 2016, with data becoming available in 2018 (DECC 2014h).

In 2009 and as part of its 'Environmental Accounts', the ONS began the annual publication of the 'Energy Accounts' (EA). The EA also uses the SIC system to allocate energy demand to specific industries and much of the data is derived from the DUKES. Though some data is supressed, for some sectors a more detailed account is given than is available in the DUKES. Data for the tables is provided by consultancy firm Ricardo-AEA (formerly AEA). This company maintains the National Atmospheric Emissions Inventory (NAEI) for the Department of Environment, Food and Rural Affairs (Defra) and the Greenhouse gas inventory (GHGI) for DECC. Combustion emissions in the NAEI and GHGI are based on fuel consumption data and it is this data which forms the EA. Accordingly there is a strong link between top-level emissions statistics, the Environmental Accounts, and the EA.

The boundary of energy data in the DUKES and EA differs in some areas. In-line with the ONS economic accounts, e.g. the Blue book, which is in-turn organised for the accounting structure of the UN System of Environmental Economic Accounts (SEEA), the boundary of the EA is set by the residence principle. That is, it counts the energy demand of UK household and business travel abroad and discounts that of non-UK travel into the UK. This is distinct from the DUKES which sets its boundary by territory. However, as industrial sites are stationary installations this difference is not relevant to industry.

The structure of energy balances in the DUKES and EA also differs. The DUKES separates from the industrial user the processes that transform energy commodities, e.g. blast furnaces, whereas the EA allocates all primary and secondary forms of fuel to the industrial sectors. The sectors covered by the EA are disaggregated to a higher SIC level (between level 2 and level 4) but electricity flows are not tabulated. At higher aggregations the EA does present energy totals which include the net demand of electricity, and a reallocated energy demand in which the energy demanded for electricity generation and delivery is allocated to the sectors. However, because input and output electricity flows are not separately presented, there is insufficient information to construct a transparent energy system akin to the DUKES balances.

At the level of industrial energy demand there are further discrepancies between the two sources. Firstly, the DUKES energy balance includes an account of heat (typically steam) trade between sectors. In doing so the energy demanded for heat export is stripped from the final energy demand of industrial sectors. In the EA this energy remains allocated to the sectors. Secondly, only coal and natural gas is allocated specifically to autogeneration activities in the EA whereas

the DUKES accounts for all fuels used for this purpose. Thirdly, there is a profound discrepancy between the two data sets relating to the use of petroleum products, in particular other petroleum gas (OPG) and gas oil.

Demand for OPG, also known as refinery gas, in the EA is inferred from an extensive coverage of data collected for the EUETS in, among others, the refineries sector, which is subsequently used for the UK GHGI (MacCarthy and Thistlethwaite 2010). Also included within the category of OPG is an estimate of steam cracker fuel gas consumption (Webb et al. 2012). The allocation of OPG to the refinery and chemicals sectors is inconsistent with that of the DUKES, which significantly under-reports its use. Conversely there is a significantly lower demand for gas oil reported in the EA than in the DUKES across all sectors of industry. At least some of this discrepancy is related to the inconsistent use of nomenclature for certain products by the data providers (ibid.).

To support the analysis in this chapter a simple data bridge between the DUKES and EA datasets was constructed. This may be referred to in section A2 of the Appendix.

3.1.2 Emissions scheme data

Climate Change Agreements (CCAs) for industrial sectors affected by the UK Climate Change Levy (CCL) are defined on the basis of accurate energy and combustion CO_2 emission benchmarks and targets. Data from the first phase of the scheme was published biennially from 2002 to 2010 (World and Scott 2011). However, the data is aggregated to primary energy without fuel split and it is not always clear where sector boundaries differ from statistical sources.

CO_2 emissions data verified under the EUETS are also accessible from the public domain (Environment Agency 2013). Data is presented on an installation, or site, basis as opposed to economic category. In a meso-level analysis of industrial heat loads by McKenna (2009), EUETS data was combined with fuel splits and other informed assumptions to back-calculate site energy demands. This work was updated and elaborated on by Norman (2013) and compared with energy data from CCAs and ECUK.

3.1.3 Bottom-up data

While meso-level assessments have provided greater insight into industrial energy and emissions than national statistics alone, further detail is required for a bottom-up assessment. Bottom-up assessments are process-based, as opposed to being based on economic classification or installation. It is therefore necessary to obtain data at the process or process plant level.

Because of the varied nature of industry in terms of process, it is necessary to obtain data on a sector-by-sector basis. This data is not generally available from secondary sources and must therefore be sourced directly from representative statistical bodies and trade associations, e.g. the

ISSB and Mineral Products Association (MPA) respectively. While these bodies hold high quality data, there are limits on how much of it may be accessed for study as the data, which is collected directly from companies, is subject to commercial confidentiality restraints.

From a survey of these trade associations and statistical bodies it was discovered that data from long-established homogenous energy intensive sectors, such as cement and steel, was obtainable. These sectors in particular could also be supplemented by international sources such as the Cement Sustainability Initiative (CSI 2013) and past publications of World Steel, formally the International Iron and Steel Institute (IISI 1990, 1996). Conversely, the heterogeneous sectors are less accessible due to their complex, dynamic and cumulative structure of processes, and because their trade associations are less equipped or willing to disclose detailed information.

Some existing studies of UK industry at the process level were, though out-of-date, identified as useful sources of bottom-up information. These include the aforementioned PA studies of the 1980's Energy Audit Series (1979, 1980, 1982) and a forecasting study by Langley (1984b), and individual studies including one of the iron and steel sector by Michaelis (1998).

3.2 Top-down structure

3.2.1 Boundary considerations

The top-down structure of industry depends on the scope defining the sector. The dictionary definition of industry[10], as an activity in its own right, is an 'economic activity concerned with the processing of raw materials and manufacture of goods in factories' (Stevenson 2010). This is synonymous with the definition of the manufacturing sector which is defined for the UK SIC (ONS 2009) as:

'The physical and/or chemical transformation of materials, substances or components into new products. The material, substances or components are raw materials which are products of agriculture, forestry, fishing or mining as well as products and semi-finished products of other manufacturing activities.'

The manufacturing sector covers SIC divisions 10-33, which includes the manufacture of products for use as fuel. Fuel product manufacture is excluded from the definition of industry in the DUKES energy balances and instead placed into energy and transformation categories. These energy product industries include petroleum refining (19.2), coke and other solid fuel production (19.1), and processing of nuclear fuel (24.46). Production of blast furnace gas (part of 24.1) is also included though this fuel is a by-product of iron manufacture rather than fuel manufacture. At the same time DUKES includes some non-manufacturing subsectors within industry including:

[10] This word should not be confused with its generic definition 'a particular form or branch of economic or commercial activity' (Stevenson 2010), e.g. the services industry.

other mining activities including minerals (08); water, sewage and waste activities (36-39); the construction sector (41-43). However, these additional activities have a relatively minor impact on total industrial energy and emissions[11].

The exclusion of fuel products manufacture from the DUKES definition of industry is necessary for the structure of its aggregate energy balances and to create a measure of final energy demand of secondary fuels by industry. However, this structure is incompatible with both installation-based modelling and bottom-up modelling because it splits manufacturing sites and process chains. Non-energy use (NEU) of fuels and autogeneration activities are also separated from industry whether or not they have a locational or technical link with the industrial process. These issues and other boundary considerations are explained in more detail below.

3.2.1.1 Fuel product manufacture

In the iron and steel sector, coke ovens are integral to the functioning of the blast furnace and both processes are integral components of the steelworks site. Indeed, the main purpose of the blast furnace is to manufacture iron so it is central to the definition of the sector. Blast furnace gas is also used exclusively at the steelworks site and, along with coke oven gas, forms part of an essentially isolated energy management system.

Distillation, cracking and reforming processes are integral processes of manufacturing sites in the petroleum refineries and petrochemicals sectors. As with iron and steel, there are numerous intermediate and by-product fuels linking process plant, boilers and generators. In contrast to iron and steel though, many fuel products are exported to sectors outside of industry, e.g. transport.

3.2.1.2 Autogeneration and heat sold

In several industrial sectors it is necessary to utilise surplus by-product gasses for heat and power generation. The processes are technically interdependent with this generation and it can be misleading to separate them. For example, blast furnace gas can only realistically be used in the iron and steel sector and it has a particularly high carbon density. The balance in its use between the blast furnace stoves and generating plant can vary emissions significantly at each plant but have no net effect on emissions in the sector.

The methodology used in the DUKES for allocating CHP plant to industrial sectors (DUKES tables 7.8 and 7.9) differs from that for industrial autogeneration (DUKES table 1.9) (Judd, A., DECC, pers. corr., September 2013). The greatest inconsistency relates to the chemicals sector. Allocated to this sector are CHP plant that are elsewhere classified as major power producers

[11] Provided that the emission of methane from landfills is not included.

(MPPs). For example, the aggregate energy balances separate fuels for MPP generation from industry.

The relationship with industry and heat generation is not clear cut and gives rise to further inconsistency. A large proportion of autogeneration across industry derives from CHP. The DUKES estimates for CHPs an amount of fuel for the electricity component of generation and an amount of fuel for the heat component of generation. Fuel for heat which is exported from its sector is allocated to 'heat generation', leaving fuel for heat which is used internally remaining as part of the industrial sector's final energy demand. The fuel for these external heat flows, or 'heat sold', covers heat from industrial MPP CHP whereas the allocation for industrial autogeneration excludes MPPs. Thus industry appears to be based on the simultaneous use of two different scopes for the allocation of generation plant to industry. This discrepancy is most significant for the chemicals sector. Meanwhile for the iron and steel sector, fuel for both heat and power generation is allocated to autogeneration. This is inconsistent with the allocation for other industrial sectors and could lead to misleading conclusions about the efficiency of industrial autogeneration.

3.2.1.3 Non-energy fuel use

The DUKES does not allocate to industry any demand for NEU fuels. However some of these fuels are associated with industrial process-related GhG emissions and some are used indirectly as by-product fuels resulting in combustion-related emission (DECC 2007b).

Petrochemical feedstock such as naphtha, ethane, propane, butane, and gas oil are fed to steam crackers in the chemicals sector for the production of lower olefins. Fuel-grade process off-gas is subsequently combusted to provide process heat. Most of the feedstock energy and carbon is locked into the process product and later stored in forms such as plastic and rubber. Though this energy and carbon is ultimately released if combusted at a later stage.

Natural gas is used as a feedstock in steam reformers to produce hydrogen for ammonia synthesis and releases a pure stream of CO_2. Natural gas is also used as a feedstock in acetic acid and acetic anhydride production units which produce hydrogen off-gas used in an adjacent ammonia plant (DECC 2007b). In this case, carbon monoxide process off-gas may be combusted as a fuel.

A proportion of the petroleum coke designated as an NEU fuel in the DUKES is known to be used for combustion in cement kilns. Some is also used for the production anodes with emissive industrial applications as well as for fuels which are combusted in the domestic sector (DECC 2007b). The discrepancy with petroleum coke was mostly addressed in the latest edition of the DUKES (DECC 2014b).

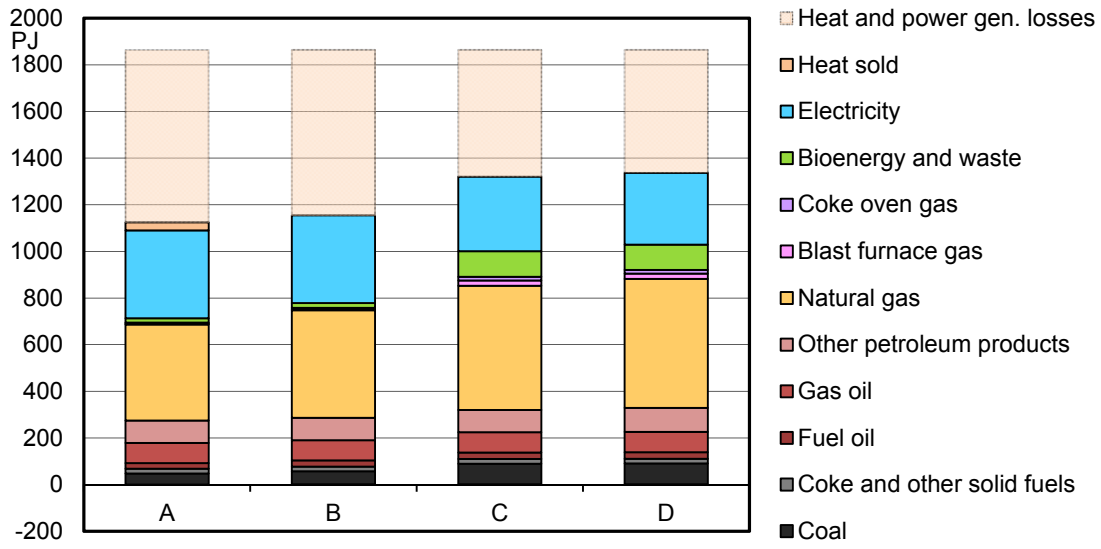

Figure 3-1: Top-down representations of industry in 2010 with different scopes for encompassing heat and power generation

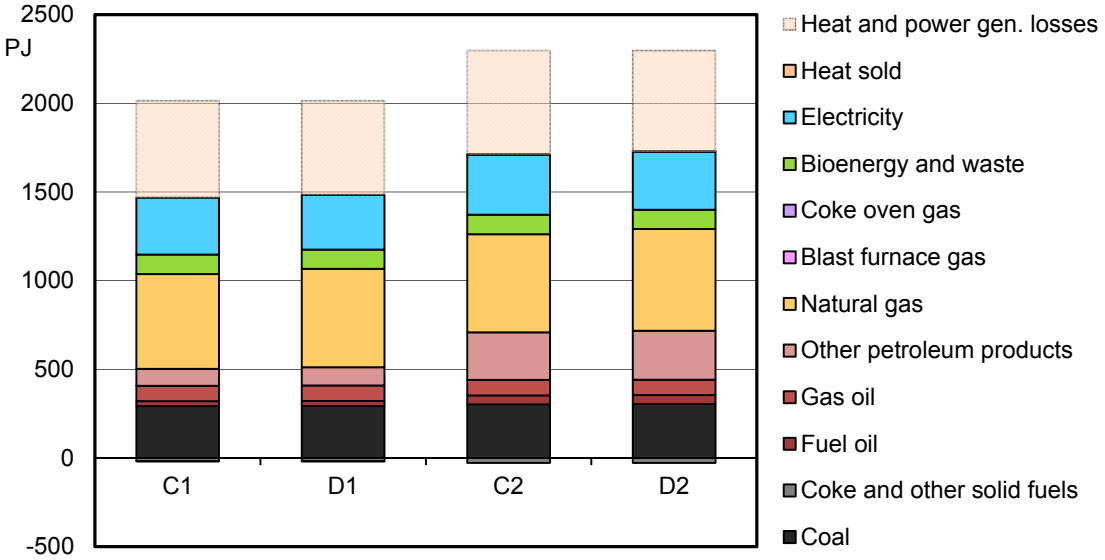

Figure 3-2: Top-down representations of industry in 2010 with different scopes for industrial activities

3.2.2 Definitions

Data from the DUKES may be used to construct appropriate scopes for linking bottom-up industrial sector modelling. Figure 3-1 compares four top-down scopes for encompassing heat and power generation. Scope A is the reference scope based on the final energy demand for industry defined in the DUKES aggregate energy balance. Scope B includes fuels for heat sold from industry. Scope C is as scope B plus fuels for autogeneration. Scope D is as scope C plus fuels for autogeneration activity from chemicals CHP also classified as MPP. For the sake of completion, direct energy loss from imported heat and power was calculated and is also shown. Including these losses, industry demanded 1864PJ in 2010.

Figure 3-2 displays two different definitions of industry with heat and power scopes C and D. Definition 1 includes coke oven and blast furnace energy as these activities are classified by the

SIC as manufacturing and virtually all associated fuel product is consumed by industry. Definition 2 is as definition 1 plus petroleum refineries and all other fuel manufacture. These additional activities are also defined in the SIC as sectors of manufacturing though most of the associated fuel product, e.g. petrol, is exported to other economic sectors. Due to data limitations, only demand for OPG in the autogeneration category of the DUKES aggregate energy balance was allocated to refineries autogeneration.

3.2.3 Primary energy factor

Primary energy demand is the energy that is drawn from natural raw materials and flows. In order to estimate the primary energy demand for the industrial sector it is necessary to trace its energy demand upstream through the transformation system to the level of primary energy drawn. Primary energy equivalents have already been calculated for the ECUK, however these are limited to fuel aggregations and the methodology used to calculate them is not shown. To calculate the primary energy equivalent for all primary and secondary energy flows received by the final demand sectors, the methodology used in a previous study of the UK energy sector (Chapman et al. 1974) is applied here.

The energy producing components of the transformation system are interdependent with one another for their energy requirements. That is, the loss associated with the production of each energy flow demanded at a component may include the part of the loss associated with production from that component. For example, blast furnace gas is combusted for electricity generation and some of this electricity is required by the blast furnace, which produces the gas. The overall system can be modelled to determine these interdependent factors of transformation.

Energy through a transformation system component can be represented by the energy balance in Equation (3-1), where E is energy, ε is the reciprocal of energy transformation efficiency, subscript p denotes primary input, subscript i denotes the transformation system component of which E_i is the net energy production, and subscript j denotes another transformation component from which E_{ji} is delivered to i.

$$\varepsilon_i E_i = E_p + \sum_j \varepsilon_j E_{ji} \qquad (3\text{-}1)$$

Applying this balance to each component of the energy transformation system in 2010 gives the set of eight linear equations (3-2) - (3-9), where subscript p is petroleum refineries, c is coke ovens, s is solid (patent) fuel manufacture, b is blast furnaces, em is electricity generation from major power producers, ei is electricity generation from industrial autogenerators, eo is electricity generation from other autogenerators, and h is traded heat generation. To construct this table the petroleum and manufactured fuel categories of the DUKES aggregate energy balance were split into their component fuels. To view this split, refer to Table A-2, section A3 of the Appendix.

$$3149\varepsilon_p = 3516 + 0\varepsilon_c + 0\varepsilon_s + 0\varepsilon_b + 12\varepsilon_{em} + 0\varepsilon_{ei} + 6.3\varepsilon_{eo} + 3.9\varepsilon_h \quad (3\text{-}2)$$

$$142\varepsilon_c = 174 + 0\varepsilon_p + 0\varepsilon_s + 2.6\varepsilon_b + 0.2\varepsilon_{em} + 0\varepsilon_{ei} + 0.1\varepsilon_{eo} + 0\varepsilon_h \quad (3\text{-}3)$$

$$10\varepsilon_s = 11 + 0\varepsilon_p + 0\varepsilon_c + 0\varepsilon_b + 0\varepsilon_{em} + 0\varepsilon_{ei} + 0\varepsilon_{eo} + 0\varepsilon_h \quad (3\text{-}4)$$

$$26\varepsilon_b = 33 + 0.18\varepsilon_p + 89\varepsilon_c + 0\varepsilon_s + 1.1\varepsilon_{em} + 0\varepsilon_{ei} + 0\varepsilon_{eo} + 0\varepsilon_h \quad (3\text{-}5)$$

$$1046\varepsilon_{em} = 2971 + 48\varepsilon_p + 9.2\varepsilon_c + 0\varepsilon_s + 19\varepsilon_b + 0\varepsilon_{ei} + 0\varepsilon_{eo} + 0\varepsilon_h \quad (3\text{-}6)$$

$$57\varepsilon_{ei} = 206 + 2.8\varepsilon_p + 1.5\varepsilon_c + 0\varepsilon_s + 0.6\varepsilon_b + 0\varepsilon_{em} + 0\varepsilon_{eo} + 0\varepsilon_h \quad (3\text{-}7)$$

$$54\varepsilon_{eo} = 102 + 2.8\varepsilon_p + 1.5\varepsilon_c + 0\varepsilon_s + 0.6\varepsilon_b + 0\varepsilon_{em} + 0\varepsilon_{ei} + 0\varepsilon_h \quad (3\text{-}8)$$

$$57\varepsilon_h = 104 + 2.8\varepsilon_p + 1.5\varepsilon_c + 0\varepsilon_s + 0.6\varepsilon_b + 0\varepsilon_{em} + 0\varepsilon_{ei} \quad (3\text{-}9)$$

The eight equations have eight unknowns and can thus be solved mathematically, e.g. using the Gaussian elimination algorithm. Results are summarised in Table 3-1 and two measures are distinguished: primary energy commodity factor and primary energy factor. The primary energy commodity factor links final energy demand to the equivalent demand in primary energy commodities, which include: coal, primary oils, natural gas, bioenergy and waste, and primary electricity. The primary energy factor links final energy demand to the primary resource and in doing so includes the energy required in extracting or capturing the primary energy carrier from nature. The primary energy factor is also shown after adjusting for energy transfers and links final energy demand in the DUKES precisely with the headline figures for primary energy demand.

	Energy carrier	Primary energy commodity factor	Primary energy factor	Primary energy factor (adjusted)
ε_p	Petroleum products	1.09	1.13	1.13
ε_c	Coke oven products	1.34	1.35	1.34
ε_s	Solid (patent) fuels	1.02	1.03	1.02
ε_b	Blast furnace gas	6.00	6.05	6.02
ε_{em}	Major power producer electricity	2.79	2.87	2.85
ε_{ei}	Industrial autogenerated electricity	5.59	5.83	5.80
ε_{eo}	Other autogenerated electricity	2.17	2.32	2.31
ε_h	Heat	1.90	1.98	1.97
E_p	Coal	1	1.007	1.001
E_p	Oil	1	1.041	1.035
E_p	Natural gas	1	1.053	1.047
E_p	Bioenergy and waste	1	1.100	1.090
E_p	Primary electricity	1	1	1

Table 3-1: Primary energy factors and primary energy carrier factors of the 2010 UK energy system

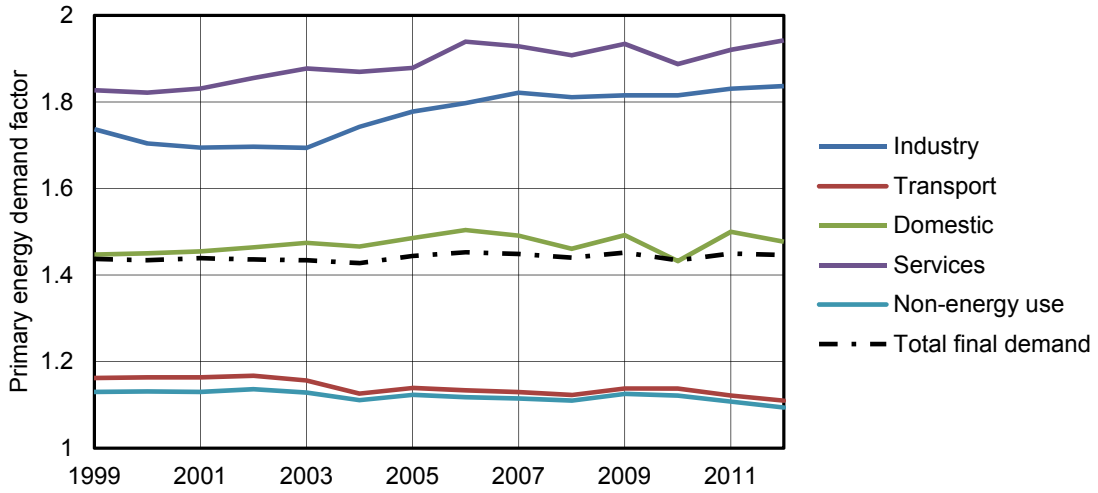

Figure 3-3: Estimated primary energy demand factors for DUKES energy demand sectors

By applying the adjusted primary energy factors to the fuel splits of each of the main energy demand sectors, a sectoral primary energy demand factor may be ascribed to them. Figure 3-3 shows the result of this assessment for the period 1999-2012. Transport and non-energy use have relatively low factors as these sectors are dominated by applications of petroleum product combustion. The services sector has the highest factor as its demand is dominated by electricity. The factor for industry is high owing to its relatively high electricity demand and use of secondary fuels. The increasing trend in sectoral factor for industry and services is largely down to a general electrification of activities over time.

In the calculation of primary energy commodity factors, E_p of equation (3-1) is the direct input of primary energy commodities. In the calculation of primary energy factors, E_p includes direct primary input and the inputs demanded in coal mining, oil and gas extraction, and pumped storage. Oil and gas extraction is split between primary oils and natural gas by their ratio of indigenous production, while pumped storage is allocated to natural gas only. The DUKES energy balance also includes in the energy sector the term 'other' and this has been allocated to bioenergy and waste fuel supply.

For each primary energy commodity, the primary energy factor is calculated as the energy demanded in the relevant extraction and supply activity plus the energy of the primary energy carrier itself. In this calculation, primary energy commodity factors are applied to all inputs and the resulting primary energy factors are reapplied to the original primary inputs, E_p, of equation (3-1). This process is repeated to iterate out accurate primary energy factors of all primary and secondary energy carriers. The primary inputs shown in equations (3-2) - (3-7) are the primary inputs after iteration.

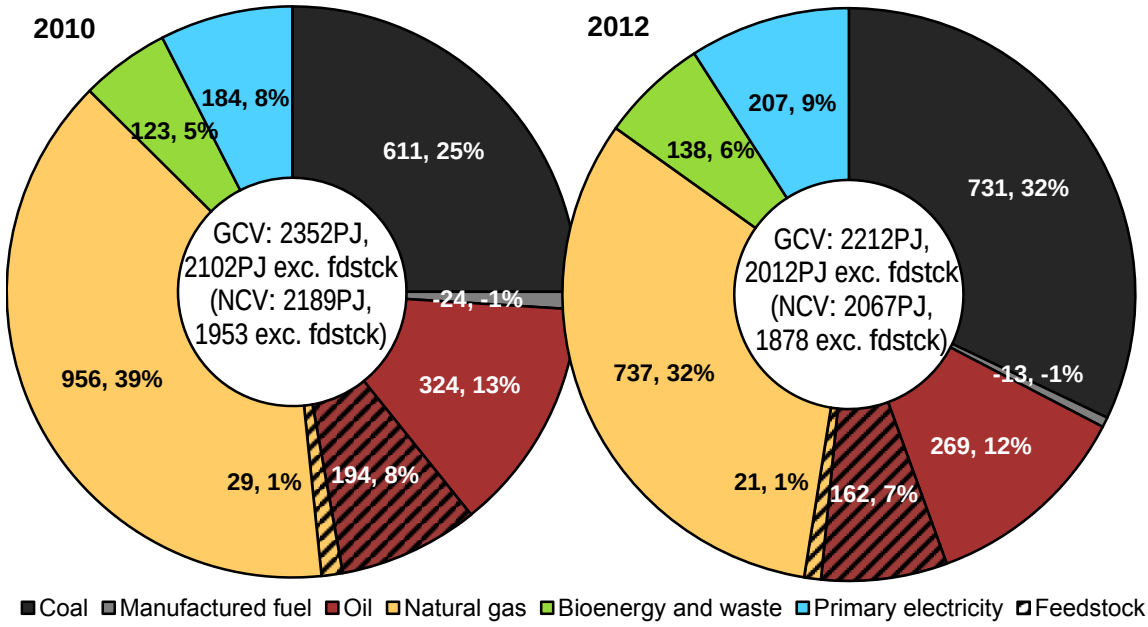

Figure 3-4: Primary energy demand in the UK industrial sector (scope C1) in 2010 and 2012

3.2.4 Primary energy and NEU

Total NEU in the UK was 382PJ in final energy demand (428PJ in primary energy demand). About half of this is petrochemical feedstock used in the production of lower olefins. Notable exclusions from manufacturing include the use of bitumen in road surfacing and weather proofing applications, and lubricants for transport applications (DECC 2007b). Some petroleum coke is used to manufacture domestic fuels and so may be allocated to industrial definition 2 only along with miscellaneous refinery products, which are assumed to be used internally by the refineries sector.

Figure 3-4 shows the primary energy demand of industry C1 in 2010 and 2012. The base year is compared with 2012 to express the significant switch to coal that occurred that year. The switch is mostly attributed to a relative increase in the use of coal by MPPs.

3.2.5 Greenhouse gas emission

GhG emissions may be divided into 'combustion emissions' or 'process emissions' which derive, respectively, from the combustion of carbon-based fuels or from reactions which liberate greenhouse gasses from process feedstock. Combustion emissions may be further divided into direct and indirect emissions. Direct combustion emission arises from the combustion of fuels by the user. Indirect combustion emission arises from that relating to the production of energy imported by the user. This is conventionally applied to electricity and heat import though, as indicated in the above analysis, exists for all imported energy forms and ultimately links to primary energy demand.

The Greenhouse Gas Protocol of the World Resources Institute and World Business Council for Sustainable Development (WBCSD) define different scopes for GhG reporting and related emission factors (EFs) are published by Defra and DECC (AEA 2012). Scope 1 is direct combustion emission as defined above. Scope 2 includes direct combustion emission resulting from the generation of electricity or heat which may in turn be imported or exported. Scope 3 is the emission associated with the extraction and transport of primary fuels and the refining, storage and distribution of fuel products. Indirect emission relating to electricity may be measured on a demand basis whereby emissions associated with electricity losses are counted (ibid.). This measure incorporates scope 2 and elements of scope 3, and is referred to hereon as scope 2/3.

Industrial process emissions are estimated and published for the UK GHGI (DECC 2014g) of which the following key categories are described here:

- **Cement production** covers CO_2 liberated from the calcination of limestone (calcium carbonate) in cement kilns.
- **Lime production** covers CO_2 liberated from the calcination of limestone and dolomite (calcium magnesium carbonate) in lime kilns.
- **Limestone and dolomite use** covers the use of these materials for slag forming in sinter plant, a fluxing agent in basic oxygen furnaces, and sources of calcium and magnesium oxide in glass furnaces. Limestone and dolomite is also used directly in blast furnaces but this CO_2 is effectively counted through the combustion of blast furnace gas.
- **Soda ash production and use** covers emissions relating to soda ash (sodium carbonate). Soda ash production in the UK uses the Solvay process for which it may be assumed that CO_2 is sequestered in the product. However the subsequent use of soda ash in glass furnaces for soda-lime glass production emits process CO_2. Soda ash is also used in the food and drink, and pharmaceuticals sectors, though in much smaller amounts.
- **Ammonia production** covers methane steam reforming from which CO_2 is emitted as a by-product.
- **Nitric acid production** covers the emission of nitrous oxide (NO_x) formed from the oxidation of ammonia at nitric acid plants. Since 2011 all plants have abatement equipment installed.
- **Iron and steel production** covers CO_2 from the flaring of blast furnace gas and basic oxygen furnace gas at integrated steelworks, and the combustion of graphite electrodes at electric arc furnaces. Minor emissions of NO_x from the oxidation of nitrogen at high temperatures and of other minor gasses from scrap contaminants are also allocated to the electric arc furnace, and emissions from lubricant evaporation at rolling mills are included.
- **Fletton bricks** covers the emission of CO_2 deriving from the use of Lower Oxford clay containing carbonaceous material which performs the role of a fuel in brick firing.

- **Aluminium production** covers the emission of CO_2 and other gasses from the consumption of carbon anodes in the primary smelting of aluminium.
- **Other – chemicals industry** covers the use of a range of minor chemical products leading to GhG emission.

3.2.6 Summary and adjustment

Table 3-2 summarises different measures of energy demand and GhG emissions for the UK industrial sector in 2010. Scope 2/3 emissions are measured on an actual and credit basis. Actual emission is the emission calculated for each individual electricity or heat flow based on the efficiency and fuel mix of its generation. Credit based emission assumes that electricity and heat generation from industry displaces that from grid and district systems respectively. The higher emissions resulting from this actual basis indicate that, despite transmission losses, average industrial autogeneration is more emissions intensive than grid electricity. This is mostly attributable to a need in the iron and steel sector to use carbon intensive blast furnace gas and the way in which this particular sector is modelled in the DUKES, whereby fuel for electricity and non-traded steam generation is allocated exclusively to autogeneration. Generally the other industrial sectors perform with relatively high generation efficiency and low emission.

Different measures of primary energy are also shown. Firstly, a simple primary energy measure including direct energy input plus direct energy inputs required for delivered or exported heat and power is shown. This relates to Figure 3-1 and Figure 3-2. Secondly, primary energy is calculated by applying the primary energy factors in Table 3-1 to net heat and power, and fuel inputs. Thirdly, net primary energy is calculated by applying primary equivalents also to fuel outputs. This measure does not change with industry scope or definition because all outputs from energy transformation plant are ascribed with complete primary equivalence whether or not those outputs are destined for the industrial sector. This is necessary to avoid double counting with other demand sectors for which a primary energy demand is calculated. In particular this affects industry definition 2 in that energy demand in the petroleum refineries sector that is allocated to petroleum products not delivered to the industrial sector is not defined as an industrial energy demand. A small amount of coke oven product is also traded though this was approximately balanced in 2010.

A number of minor adjustments have been made to the DUKES dataset to reflect changes in the use of NEU fuels and to incorporate an update in the allocation of coal between industry and coke ovens (DECC 2007b, 2014b). Of the NEU fuel listed in the DUKES an estimated 49PJ of petrochemical feedstock was ultimately combusted in the form of fuel grade by-product gas (Neelis et al. 2003). 11PJ of petroleum coke was combusted in industry of which 1PJ was in the cement sector. Conversely, benzole and tars were not combusted and are reallocated to NEU. For more detail refer to section A3 of the Appendix.

	Energy, PJ (GCV)							GhG emission, $MtCO_2e$					
Industry scope (definition) ID	Fuel	Electricity	Heat	Direct energy	Simple primary energy: heat/power direct losses (credit basis)	Primary energy: fuel inputs + heat/power primary factors (credit basis)	Net primary energy equivalent	Scope 1: direct emission (combustion and process)	Scope 1-2: calculated scope 2 EFs	Scope 1-2/3: calculated scope 2/3 EFs (credit basis)	Scope 1-2/3: published scope 2/3 EFs - grid rolling avereage (credit basis)	Scope 1-2/3: calculated from primary energy - credit basis	Scope 1-3: published scope 2/3 EFs - grid rolling avereage and credit basis
A	713	376	34	1,124	1,864 (1,821)	2,040 (1,896)	2,040	54	111	115	113 (110)	-	126
B	778	376	-1	1,153	1,864 (1,821)	2,040 (1,902)	2,040	58	111	115	113 (112)	-	126
C	1,001	319	-1	1,319	1,864 (1,885)	2,040 (2,075)	2,040	70	111	115	113 (117)	-	127
D	1,029	308	-1	1,336	1,864 (1,882)	2,040 (2,074)	2,040	72	111	115	113 (117)	-	127
C1	1,129	320	-1	1,448	1,995 (2,016)	2,040 (2,102)	2,040	78	119	122	121 (124)	131	138
D1	1,156	309	-1	1,465	1,995 (2,014)	2,040 (2,100)	2,040	80	119	122	121 (124)	131	138
C2	1,344	338	0	1,682	2,264 (2,283)	2,410 (2,461)	2,040	92	134	138	137 (140)	152	157
D2	1,371	327	0	1,699	2,264 (2,280)	2,410 (2,459)	2,040	93	134	138	137 (140)	152	157
After adjustment:													
A	775	376	34	1,185	1,925 (1,883)	2,103 (1,961)	2,103	57	114	118	117 (114)	-	130
B	840	376	-1	1,215	1,925 (1,883)	2,103 (1,967)	2,103	61	114	118	117 (115)	-	130
C	1,062	319	-1	1,380	1,925 (1,946)	2,103 (2,136)	2,103	74	114	118	117 (120)	-	132
D	1,090	308	-1	1,397	1,925 (1,943)	2,103 (2,135)	2,103	75	114	118	117 (120)	-	132
C1	1,182	320	-1	1,502	2,049 (2,070)	2,103 (2,164)	2,103	80	121	125	123 (127)	134	142
D1	1,210	309	-1	1,518	2,049 (2,067)	2,103 (2,162)	2,103	82	121	125	123 (127)	134	142
C2	1,398	338	0	1,736	2,318 (2,337)	2,467 (2,517)	2,103	94	137	141	139 (143)	154	161
D2	1,425	327	0	1,753	2,318 (2,335)	2,467 (2,514)	2,103	96	137	141	139 (143)	154	161

Table 3-2: Top-down summary of energy and GhG emissions in the UK industrial sector, derived from the DUKES (DECC 2013a)

3.3 Bottom-up structure

Bottom-up 2010 baselines for key energy intensive homogenous industrial sectors are presented here. Much of the data was obtained from sources associated with the sectors. Where primary energy is referred to it is the simple primary energy. Iron and steel, cement, lower olefins, and ammonia are covered in detail in chapters 4-6.

3.3.1 Homogenous sectors

A sector is homogenous if it can be modelled by a single manufacturing process or process system of which the output can be meaningfully represented by a single physical measure.

3.3.1.1 Iron and steel

The iron and steel sector is the largest energy using homogenous sector of UK industry. Most energy is used for smelting iron from iron ore at around 1500˚C in a blast furnace. There are 7 blast furnaces at 3 integrated steelworks sites. The bulk of sector energy demand derives from coal, most of which is converted to coke in coke ovens. Coke is fed into the blast furnace where it is required for thermal energy but also for its mechanical properties and as a reducing agent. Iron is converted into steel which is then casted and finished into saleable industry products. About one fifth of total steel production is converted directly from scrap in electric arc furnaces. The physical unit of production for the sector is tonnes of crude steel (tcs).

Sector energy demand in 2010 was 197PJ of which net fuel demand was 184PJ and electricity import was 13PJ (ISSB 2012a). Total production was 9.7Mtcs resulting in a direct SEC of 18.9GJ/tcs and primary SEC of 22.5GJ/tcs. Direct GhG emission was 16.3MtCO_2e and total emission, including that attributable to electricity import, was 19.4MtCO_2e.

It should be noted that 2010 was an atypical year as the large blast furnace at Teesside was temporarily shut-down. By comparison, 264PJ of fuel and 17PJ of purchased electricity was demanded in 2007 for a production of 14.4Mtcs. Direct and total GhG emission this year was 23.9MtCO_2e and 26.4MtCO_2e respectively.

3.3.1.2 Cement

Nearly all energy demand in the cement sector is used in the production of clinker which is manufactured from limestone or chalk at up to 1500˚C in a rotary kiln. There are 13 kilns operating in the UK at 11 sites. Kiln thermal energy has historically depended on the combustion of coal but this is increasingly being substituted with fossil and biomass waste alternatives such as shredded tyres and animal meal, respectively. Nonetheless, about two thirds of GhG emission is CO_2 liberated from the calcination of limestone. After its formation, clinker is ground and mixed with other materials such as pulverised fly ash and ground granulated blast furnace slag to

produce cement. The physical unit of production for the sector is tonnes of Ordinary Portland cement (tc).

Sector energy demand in 2010 was 34.7PJ of which fuel demand was 30.8PJ and electricity import was 3.9PJ (CSI 2013, Edwards 2011). Total production was 9.4Mtc (of which 8Mt was factory made cement containing 6.8Mt of clinker) resulting in a direct SEC of 3.3GJ/tc and primary SEC of 4.4GJ/tc. Kiln thermal efficiency was 4GJ/t clinker, or 3.8GJ/t clinker in net calorific value. Direct sector GhG emission was 5.8MtCO_2e and total emission, including that attributable to electricity import, was 6.4MtCO_2e.

3.3.1.3 Paper and board

Fuel demand in the paper and board sector is dominated by CHP and boiler plant for process electricity and steam demand. Fuel demand is mostly met by natural gas though biomass is increasingly being utilised and presently accounts for about 15% of sector fuel demand. Paper is formed and dried from pulp and finished into paper products. About 80% of pulp derives from recovered paper, 15% from imported virgin wood pulp, and less than 5% from domestic pulp production. There were 49 paper mills in 2010 of which just 2 are integrated pulp and paper mills. Final energy demand at the typical mill is dominated by the dryer section in which steam heated cylinders heat paper fibres to around 100˚C (De Beer et al. 1998b). The physical unit of production for the sector is tonnes of paper and board (tpb).

Sector energy demand in 2010 was 60PJ of which fuel demand was 53PJ, electricity import was 8.5PJ, and electricity export was 1.5PJ (Morgan 2013). Production was 4.3Mtpb resulting in a direct SEC of 12.2GJ/tpb and primary SEC of about 19GJ/tpb. Direct GhG emission was 2.3MtCO_2e and total emission, including that attributable to net electricity, was 3.3MtCO_2e.

3.3.1.4 Glass

Energy demand and emissions in the glass sector are mainly associated with the glass melt furnace which operates at up to 1600˚C. The furnace is predominantly fired with natural gas and is charged with raw materials including sand mixed with lesser amounts of sodium carbonate, limestone and dolomite. The glass batch is then formed into product shapes and annealed. High recycling rates are achieved with nearly half of bulk container glass manufacture deriving from recovered glass. Large scale glass production is shared across 18 manufacturing sites (British Glass 2014). Including small batch speciality glasses, such as lead crystal and frits, there are 25 sites (Webb et al. 2012). The physical unit of production for the sector is tonnes of glass (tg).

According to British Glass (2014), about 18% of sector CO_2 emission is liberated from raw materials, while 58% results from fuel combustion and 24% from the generation of demanded electricity. Primary energy demand reported to the CCA scheme for 2010 was 35PJ (World and

Scott 2011) and process emission submitted to the GHGI was 0.4MtCO_2e (MacCarthy 2014). Representing fuel demand with natural gas and using the above information, fuel demand estimates to 26PJ and direct electricity demand to nearly 4PJ. Based on this assessment, direct GhG emission was about 1.7MtCO_2e and total GhG emission, including that attributable to electricity import, was an estimated 2.2MtCO_2e.

Production in 2010 was 3.1Mtg resulting in direct and primary SECs of 10GJ/tg and 11GJ/tg respectively. The thermal SEC of glass furnaces is reported to be about 5GJ/tg (British Glass 2014) though average operating efficiency is expected to be marginally higher due to operational intermittency and other effects.

3.3.1.5 Lime

Energy demand in the lime sector is dominated by the lime kiln from which two variants of lime are manufactured: high calcium lime and dolomite. High calcium lime is over 70% of production and is decomposed from limestone or chalk at 900-1400˚C in a vertical kiln or horizontal rotary kiln. Dolomite is decomposed from dolomitic limestone at up to 2000˚C in a horizontal rotary kiln (BLA 2013). There are 26 kilns operating from 13 sites of which 17 kilns at 7 sites are members of the British Lime Association (BLA) (Hill 2013). A significant proportion of thermal energy demand is met by natural gas with most of the remainder split between coal and waste alternatives (ibid.). The decomposition of raw material releases CO_2 and accounts for about two thirds of total direct GhG emission. The physical unit of production for the sector is tonnes of lime (tl).

In 2010 BLA members demanded 7PJ of energy of which 6.5PJ was fuel and 0.5PJ was imported electricity. Production was 1.3Mtl (Hill 2013) resulting in a direct SEC of 5.7GJ/tl and primary SEC of 6.3GJ/tl. Average thermal SEC of lime kilns was an estimated 5.3GJ/tl. Direct GhG emission of the sector was 1.36MtCO_2e and total GhG, including that attributable to electricity import, was 1.43MtCO_2e.

Assuming similar emissions intensity for associate members, direct and total GhG emission from all kilns, producing an estimated 1.55Mtl, was 1.7MtCO_2e and 1.8MtCO_2e respectively. By the same assumption for energy intensity, fuel demand was 8.3PJ and electricity import was 0.6PJ.

3.3.1.6 Ceramics

The ceramics industry is concerned with the manufacture of a number of ceramic products including bricks, refractories and whitewares. Bricks are manufactured from clay which is mixed and formed with water, dried and then fired in kilns to temperatures of 900-1100˚C. About 5% of brick production is fletton brick (World and Scott 2011), which is manufactured from Lower Oxford clay containing organic elements which burn during firing. The resulting process emission

amounts to a small fraction of total emissions from the brick sector. Fuel demand in the sector is predominantly natural gas and electricity accounts for some 8% of final energy demand (Carbon Trust 2011). The physical unit of production for the sector is tonnes of brick (tb).

According to data submitted to the CCA scheme (World and Scott 2011), primary energy demand in the brick sector was about 10PJ. Thus fuel demand was an estimated 9PJ and delivered electricity a little below 1PJ. Production was about 3.1Mt of brick resulting in direct and primary SECs of 3.2GJ/tb and 3.6GJ/tb respectively. Direct GhG emission was an estimated 0.6MtCO_2e and total emission, including that attributable to electricity import, was about 0.7MtCO_2e.

According to the CCA scheme, combustion EF of the brick sector is similar to that of the ceramics sector as a whole. Assuming the same fuel mix, fuel demand in the ceramics sector was 16PJ and electricity demand was a little over 1PJ. Direct and total GhG emission was 1MtCO_2e and 1.2MtCO_2e respectively. This covers a total production of 4.1Mt of ceramic product.

3.3.1.7 Aluminium

Primary aluminium is produced from alumina, derived from bauxite, by the Hall-Héroult electrolytic process. Aluminium is also recyclable from scrap at a fraction of the energy requirement. After the closure of the Lynmouth smelter in 2012, primary production dropped to just 60kt from 186kt in 2010. Electricity for this smelter was supplied by the Lynmouth power station, then owned by Rio Tinto, and emitted nearly 3MtCO_2e in 2010. Production is now from a single smelter, Lochaber, which operates on hydropower. Therefore the aluminium sector no longer has much relevance from an emissions standpoint.

3.3.2 Heterogeneous sectors

A sector is heterogeneous if it has two or more distinct manufacturing processes of which the combined output cannot be meaningfully represented by a single physical measure.

3.3.2.1 Chemicals

The chemicals sector encompasses a large collection of disparate processes and products. The most carbon and energy intensive processes of the sector may be analysed individually.

Central to the production of organic chemicals is the steam cracking process which manufactures lower olefins, also referred to as high value chemicals (ethylene, propylene, butadiene and aromatics), from feedstock deriving from oil or natural gas. The feedstock is primarily naphtha and ethane based, and most process fuel demand is met by fuel-grade process by-product gasses. There were four steam crackers operating at the end of 2010 and three remaining in operation today. The physical unit of production for the sector is tonnes of high value chemical (thvc). Feedstock input in 2010 was about 4Mt (DECC 2013a) leading to an estimated production of

2.8Mthvc. Based on the feedstock mix and an assessment of European cracker SEC (IEA 2009b), process fuel demand was an estimated 53PJ and electricity demand was 1PJ. Accordingly, direct GhG emission was an estimated 2.2MtCO_2e and total emission was about 2.4MtCO_2e.

Another key activity of the chemicals sector is ammonia (NH_3) production. Ammonia is synthesised from hydrogen which is primarily manufactured by steam reforming with methane from natural gas. The process is exothermic and heat is used to raise steam for other ancillary processes. The process also releases CO_2 as a by-product. Two sites produce ammonia by conventional steam reforming. Fuel and feedstock input in 2010 was 10PJ and 19PJ of natural gas respectively (ONS 2014b) for a production of about 857ktNH_3 (Webb et al. 2012). Accordingly, process emission was about 1MtCO_2e while direct combustion emission was 0.5MtCO_2e. Assuming an electricity requirement of 0.8GJ/NH_3 (IEA 2009b), total emission from the sector was an estimated 1.6MtCO_2e.

3.3.2.2 Food and drink

The food and drink sector encompasses a wide range of distinct processes producing various goods such as meat, dairy and bakery products. Processes are typically of a relatively low energy and emissions intensity and it is easier to characterise the sector by non-process specific equipment such as boiler systems, CHP plant, waste heat recovery and electric motors.

3.3.3 Summary

Direct CO_2 emissions verified under the EUETS are compared with CO_2 emissions calculated from the bottom-up assessments in Figure 3-5. Due to limitations in the EUETS dataset sourced, lower olefin and ammonia production are compared for 2008 with data published in a separate study (Element Energy 2010b). Moreover, verified emission for the Aluminium sector includes that from the Lynmouth power station only. The chart shows that the bottom-up assessment corresponds well with verified emissions. However the EUETS does not cover all sector activities, which explains why most bottom-up estimations are marginally higher.

Figure 3-6 shows the sector split for industry C1 by direct and total GhG emissions. Because of their heterogeneous nature, the food and drink sector and other chemicals were not bottom-up modelled but are defined by data in the DUKES. Other industry comprises mainly of engineering and vehicles, textiles, plastics, and any other emissions remaining. The unclassified category of DUKES mainly incorporates fuels from petroleum product data providers that could not be allocated to end users. Direct and total GhG emissions from the identified homogenous energy intensive sectors account for about 45% and 32% of total industry emissions respectively, or 51% and 34% excluding unclassified industry. As previously noted, 2010 was a year of low industrial output and production in the iron and steel sector was severely affected. Direct emissions share from iron and steel in 2007 was closer to 25%.

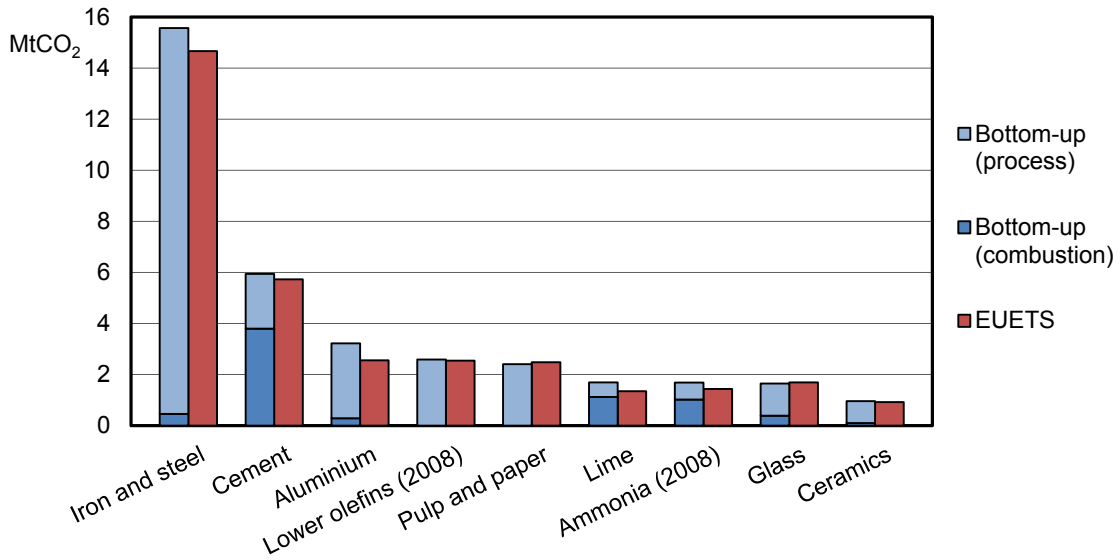

Figure 3-5: Direct CO_2 emission from key energy intensive sectors calculated by bottom-up assessment and compared with emissions verified under the EUETS (2010 unless otherwise stated)

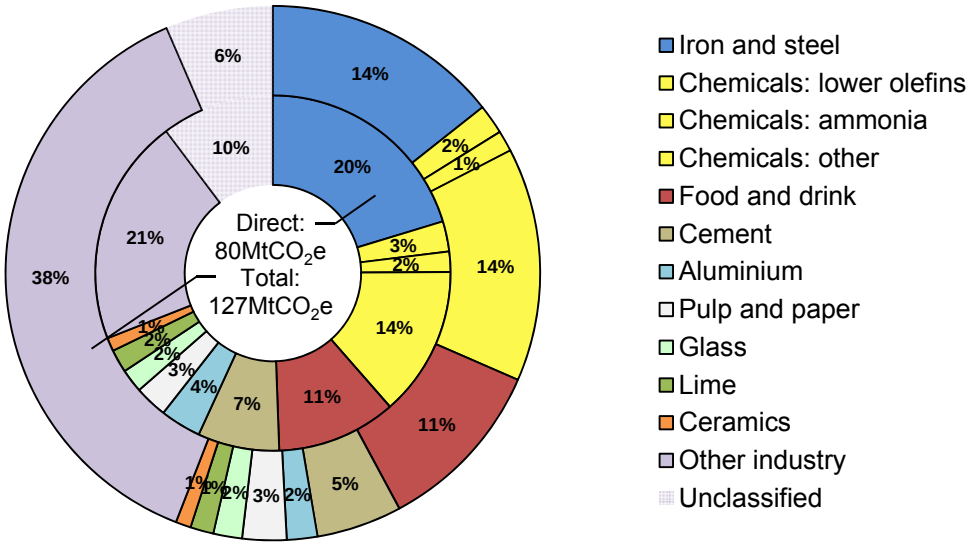

Figure 3-6: Sector split of industry C1 by direct and total GhG emission in 2010

3.4 Top-down/bottom-up link

The link between top-down and bottom-up energy and GhG emissions for the UK energy system is depicted in Table 3-3. This is a modification of the DUKES energy balance whereby top-down structure C1 is soft-linked with the bottom-up assessments. Electricity generation in the final column is negative because of the use of grid-rolling average scope 2/3 EF for electricity, which is higher than the actual grid EF in 2010. Energy 'transfers' are described in the DUKES (DECC 2013a) and encompass energy product reclassifications and backflows. Net transfers in 2010 were approximately zero thus the transfers in direct emissions may be attributed to error relating to the EFs used. Error in the final column arises mainly from the use of the grid rolling average EF. This framework is compared with the frameworks of other industry scopes in section A3 of the Appendix.

Industry C1 in 2010 accounted for 16% and 22% of direct and primary UK energy demand respectively, or 18% and 25% if NEU fuel is included. Taken as a proportion of direct energy in the demand sectors, industry accounted for 23%, or 25% including NEU fuels. In primary energy these proportions become 22% and 23% respectively. Direct and total GhG emissions attributable to industry were 13% and 20% of UK emissions respectively or, as a proportion of the demand sectors, were 23% and 25%.

Categories	Direct energy, PJ (GCV)	Direct energy, PJ (GCV)	Scope 1 GhG emission, $MtCO_2e$	Scope 1-2/3 GhG emission (credit basis; grid rolling average), $MtCO_2e$
Mining and extraction	248	225	13.1	13.9
Electricity generation	1837	1646	162.9	-10.3
Heat trading	-	-	-	-
Fuel manufacturing	252	237	13.7	17.7
Other	22	21	0.6	2.1
Losses	165	158	3.5	17.5
Demand sectors	6612	6210	341.4	504.4
Industry	1502	1409	80.4	126.6
Iron and steel	197	186	16.3	18.2
Refineries	-	-	-	-
Chemicals	283	263	14.7	21.8
Food and drink	177	165	8.7	13.4
Pulp and paper	59	54	2.4	3.4
Cement	35	33	6.0	6.5
Glass	29	27	1.7	2.2
Ceramics	18	16	1.0	1.2
Lime	9	8	1.7	1.8
Aluminium	31	29	3.0	2.3
Other industry	554	524	16.7	47.6
Unclassified	110	105	8.3	8.3
Transport	2263	2147	152.0	154.1
Domestic	2030	1879	84.9	146.9
Services	818	775	24.1	76.7
NEU	324	304	0.0	0.0
Industry	196	183	0.0	0.0
Other emission (GHGI)	-	-	68.8	68.8
Agricultural (non-combustion)	-	-	52.9	52.9
Land-use change	-	-	-7.3	-7.3
Waste management	-	-	23.2	23.2
Sub-total	9461	8802	604.1	614.1
Transfers	0	0	-6.2	-16.3
Grand-total	9461	8802	597.8	597.8
Statistics (GHGI)	9461	8802	599.8	599.8

Table 3-3: Top-down/bottom-up framework of UK energy and GhG emissions in 2010 based on DUKES data and a bottom-up assessment of industry (C1)

3.5 Historical trends

Figure 3-7 shows for the period 1990-2012 national economic output measured by gross domestic product (GDP), manufacturing output measured by index of production (IoP), and energy intensive output measured by physical output. Manufacturing includes SIC divisions 10-33. Energy intensive industry describes the group of bottom-up sectors identified for bottom-up assessment: iron and steel, cement, aluminium, pulp and paper, ethylene, lime, ammonia, bricks, and glass[12]. Since 1990 UK manufacturing has seen a decline in output relative to the economy as a whole, and energy intensive sectors of manufacturing have declined relative to the manufacturing sector as a whole. A contraction also occurred in manufacturing around turn of the century despite continued economic growth at the national level.

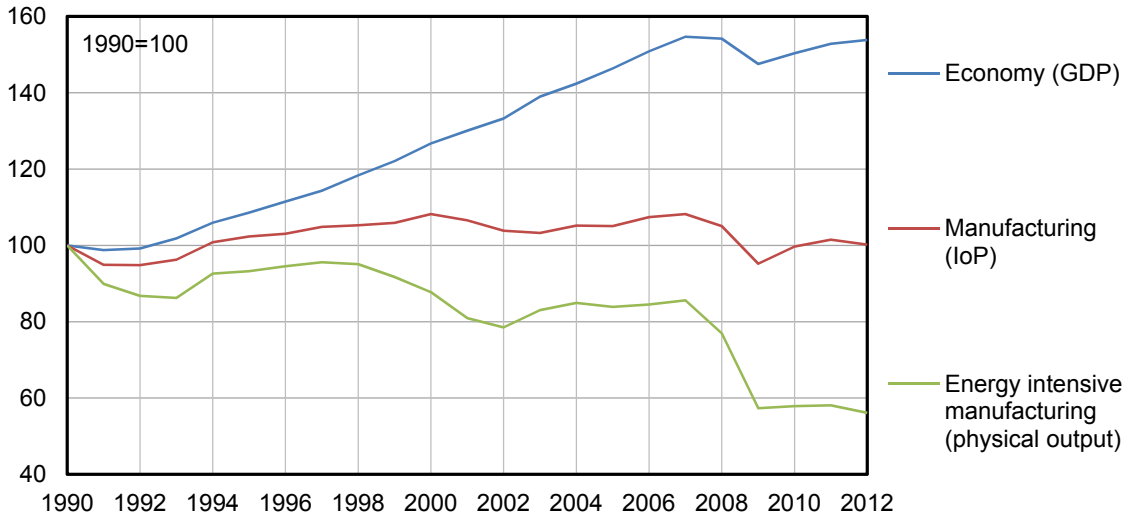

Figure 3-7: Growth comparison between different levels of the economy with different output indicators in the UK, 1990-2012, derived from Hardie and Banks (2014) and bottom-up analysis

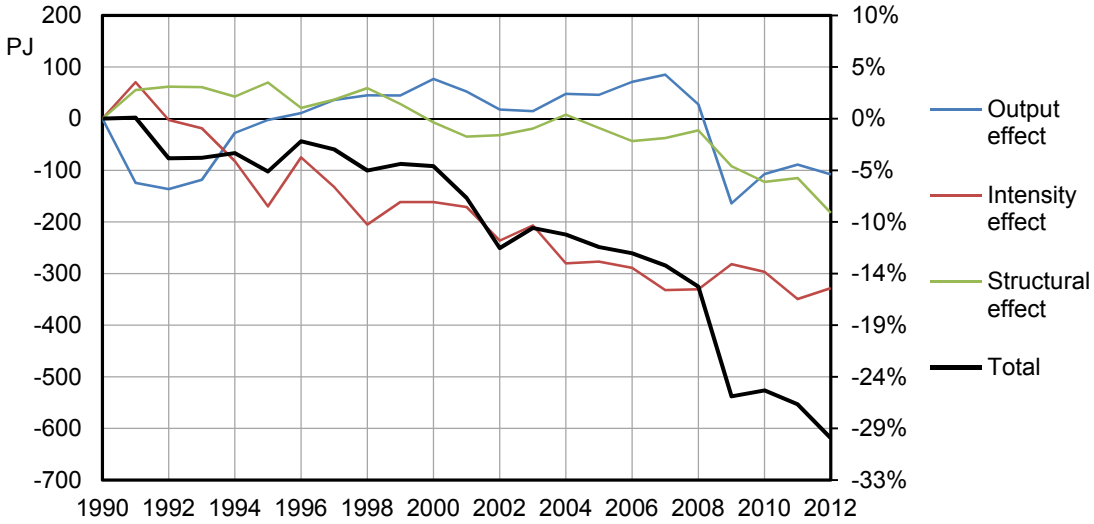

Figure 3-8: Energy demand decomposition of UK industry, 1990-2012

[12] For detail on bottom-up production and SEC trend estimations refer to section A8.1 of the Appendix.

Figure 3-8 is a statistical decomposition of aggregate direct net energy demand in the manufacturing sectors, excluding refineries and solid fuel production (industry C1), over the period 1990-2012. The LMDI I method postulated by Ang (2005), and used in a separate study on UK industry by Hammond and Norman (2012), is applied. Output is IoP in gross value added taken from the EA for 1997-2012 and extended back to 1990 by merging with detailed IoP data from the 2003 SIC structure (ONS 2012).

Energy data from the EA covering SIC industries 10-32 (excluding 19) was used and coke ovens operated in the iron and steel sector were allocated to that sector. Included in the EA dataset is energy demanded from industrial transport and off-road mobile machinery. These were excluded from the analysis here as they operate independently of processes. The EA does not include electricity demand at the disaggregated level but does include electricity generation and transmission losses reallocated to the sectors. Net electricity demand was estimated for each sector by subtracting direct fuel demand from the reallocated total and applying grid generation efficiency, calculated from the DUKES electricity supply system, to the remainder. Accordingly, fuels for autogeneration remain allocated to the sectors. The total energy demand resulting from this approach complies, after adjusting for scope, with the manufacturing total published by the EA. To see this compliance and comparison decompositions refer to section A3 of the Appendix.

Sector energy intensity reduction has generally contributed the most to aggregate industrial energy demand since 1990. Two large contractions in total output, which occurred in 1990 and 2008, came at a time of national economic recession. However, energy demand reduction from structural change took place only in the latter contraction. This can be partly explained by an increase in energy prices which accompanied the more recent recession but was absent from the first. Energy intensive sectors would self-evidently have been more affected by these price changes. Present with both contractions, however, is an increase in energy intensity. This is to be expected during periods of disruptive falls in output as industrial process plant are less likely to be optimally run. Energy intensive industry would be more affected in this case as process energy accounts for a higher proportion of sector energy demand.

It is noted that decomposition with statistical energy and economic data is subject to a number of limitations. Firstly, the DUKES dataset, and thus a large part of the EA dataset, underwent methodological changes in 1995-1996, 1998-1999, and 2000-2001 (Norman 2013). Secondly, and as explained in further detail in section 2.2.1.1.3, there exist a number of inherent errors in representing physical productivity with economic based indicators. Thirdly, any decomposition is limited by the level of data disaggregation as structural change occurring beneath this level cannot be captured.

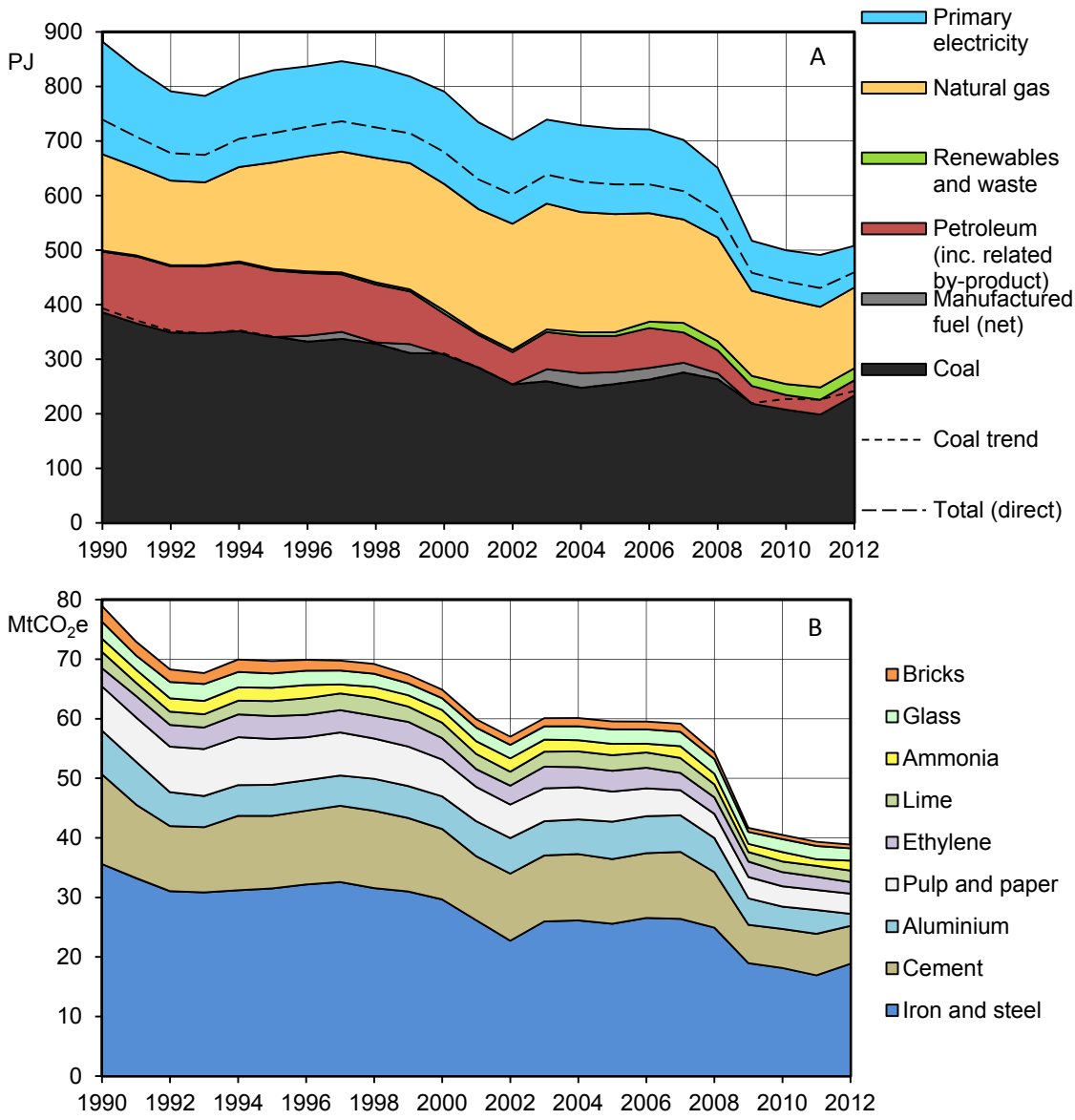

Figure 3-9: Direct energy demand (graph A) and GhG emissions (graph B) of energy intensive UK industry, 1990-2012

Figure 3-9 depicts the energy intensive portion of industry in more detail and uses a bottom-up approach. Graph A shows energy demand by fuel and graph B shows credit based scope 1-2/3 GhG emissions by sector. The iron and steel sector and the cement sector are based on detailed historical data while the remaining sectors were estimated based on changes between SEC and physical output. Process fuel gas returns in the production of lower olefins was split into petroleum and natural gas by the proportion from which process feedstock derives. For more detail on trend estimations refer to section A8.1 of the Appendix.

GhG emissions in energy intensive industry have halved from 80MtCO$_2$e in 1990 to about 40MtCO$_2$e in 2010. Over the same period, total industry has reduced from nearly 250MtCO$_2$e and by a similar proportion (DECC 2014g). With specific regard to combustion, GhG emissions in energy intensive industry have halved from 65MtCO$_2$e to 33MtCO$_2$e over the same period,

but the fall in combustion emission from total industry was about 40%. The difference is primarily attributed to the instalment of N_2O abatement equipment at adipic acid plants in the 1990s (DECC 2014k).

Emissions in Figure 3-9 are dominated by the iron and steel sector which has consistently accounted for just below half of emissions since 1990. Iron and steel also accounts for most of the requirement for coal, and thus coal has remained the dominant fuel over time. Increases in the use of natural gas relative to petroleum fuel have taken place though biomass and waste fuel alternatives have yet to make a significant impact. The iron and steel sector recently produced a surplus of coke giving rise to a significant net output of manufactured fuel in 2010 and 2011.

3.6 Discussion

The DUKES energy balance presents a useful structure for understanding the UK energy system. However, as the DUKES definition of industry does not incorporate the manufacture of energy products this raises uncertainties as to how suitable the structure is for linking with bottom-up industrial analyses. The DUKES balance splits off from industry several processes that are intrinsic to the sector's classification and can thus lead to misrepresentation. For example, in the present edition of the ECUK factsheet (DECC 2014f) it is stated that the industrial sector has reduced its demand for coke by 95% from 1970 to 2013, and that energy demand in the iron and steel sector has fallen by over 80% from 1990 to 2013. This overview does not correct for the exclusion from industry after 1995 of data for transformation plant such as blast furnaces. The blast furnace is nearly the sole consumer of coke in the UK and energy demand in the iron and steel sector has, in reality, reduced by less than half the amount stated.

The energy intensive sector generally shows a higher sensitivity to the health of the economy at large and is more greatly affected by fuel prices. The most recent recession, which saw a deep contraction in the construction sector and large energy price rises, was particularly devastating. Notwithstanding this, the recession did not yield as permanent a contraction to the iron and steel sector this time around. Whereas the integrated steelworks of Ravenscraig and Llanwern closed in 1992 and 2002 respectively, blast furnace capacity at the Teesside steelworks was only temporarily shut down from 2010. Steel production figures also show a marked recovery in 2013 (World Steel Association 2014a). At the same time cement kiln capacity has remained largely intact though less intensive industries including paper and lower olefins have seen a greater proportionate reduction in installations since 2007. The resulting structural change within energy intensive industry will almost certainly have yielded a higher energy and carbon intensity in 2013 than before the recession.

3.7 Summary and conclusions

A critique of existing energy and GhG emissions statistics was made and the DUKES energy balance was chosen as the most suitable dataset on which to base a top-down link to bottom-up assessments. There are advantages and disadvantages to the DUKES and the EA datasets. The DUKES provides a clearer account of the UK energy transformation system while the EA directly links to official national emissions statistics. A number of discrepancies between the two datasets were identified and some errors in the DUKES were corrected. A simple bridge between the two datasets was also constructed. However, reconciliation between the DUKES and the EA, and therefore the GHGI, cannot be fully completed until differences emanating from the collection of primary data by DECC and Ricardo-AEA are fully resolved.

The industrial sector was represented in a number of ways. To accommodate bottom-up studies it is necessary to include fuel manufacturing activities and industrial heat and power generation. This prevents the separation of physical process chains and harmonises more easily with installation-based data verified under the EUETS. A number of top-down structures, or scopes, were established and compared through numerous measures of energy demand and GhG emissions. Accurate primary energy factors for final energy demand were also calculated using statistical energy analysis methodology established in the wake of the first energy crisis. The factors were used to determine the relative impact of the industrial sector on primary energy resources and assist in the comparison between industrial scopes.

A bottom-up baseline was established for energy intensive industry and validated against verified EUETS emissions data. A top-down/bottom-up framework was then established to provide context to detailed bottom-up studies of later chapters and present a credible link to UK energy statistics. A top-down decomposition of historical energy demand showed through the structural change effect that energy intensive industry was most negatively affected by the recent recession. A bottom-up assessment of historical trends in energy intensive industry exhibited a halving of emissions since 1990. The iron and steel sector has remained dominant in energy intensive industry and keeps it coal intensive. Production capacity in the most intensive industries has remained largely intact since the recession indicating increases in average intensity into the short-term.

4 The iron and steel sector

In this chapter a detailed bottom-up thermodynamic and techno-economic study of the UK iron and steel sector is made. Particular attention is given to the demand for energy and materials, and emission of greenhouse gasses. The analysis also serves to demonstrate the value of assessing industries using a bottom-up technological database. Some of the data on resource flows was gathered from published sources, such as the DUKES, and some from direct correspondence with the Iron and Steel Statistics Bureau (ISSB). Much of this data was collected under the UED project for the UK Energy Research Centre. The data covers SIC (07) groups 24.1-3.

In section 4.1, the sector is introduced along with an overview of existing structure and trade. In section 4.2, an energy and emissions baseline for the sector is established and set in the context of wider impacts and decomposed historical changes. In section 4.3, efficiency improvement potential is investigated using thermodynamic (energy and exergy) analysis techniques and by comparing with best available technology (BAT). In section 4.4, technologies that could contribute to minimising resource demand and GhG emissions in the sector out to 2050 are identified and their representation for modelling is described. In section 4.5, a bottom-up techno-economic projection model is introduced and 2050 roadmaps are constructed and assessed. In section 4.6, observations and insights deriving from the chapter's analyses are discussed. In section 4.7, the chapter is summarised and concluded.

4.1 Introduction

The iron and steel industry is the largest sector of UK industry in terms of energy demand and greenhouse gas emissions. At the centre of operations is the blast furnace which reduces iron ore at high temperatures into iron with the use of carbon as a chemical reductant. The iron is converted into steel which is casted and finished into a number of industry products such as ingots, slabs, sheets, plates, bars, rods and sections consumed by a wide range of downstream sectors including construction, vehicles, metal fabricating industries and consumer goods. Steel is also converted from scrap and is the most recycled and recyclable material on the planet (BIR 2014).

The sector depends on a high throughput of natural resources with energy costs making up a significant proportion of overall production cost. The sector has always been highly energy conscious and made significant improvements to efficiency over the years. Today the sector is also subject to a raft of government programmes designed to stimulate emissions reduction but believes there is limited room left for improvement based on existing technologies (UK Steel 2011). Moreover, steel is a highly traded commodity and there is a fear that the cost associated with unilateral emissions constraints in Europe could lead to carbon leakage.

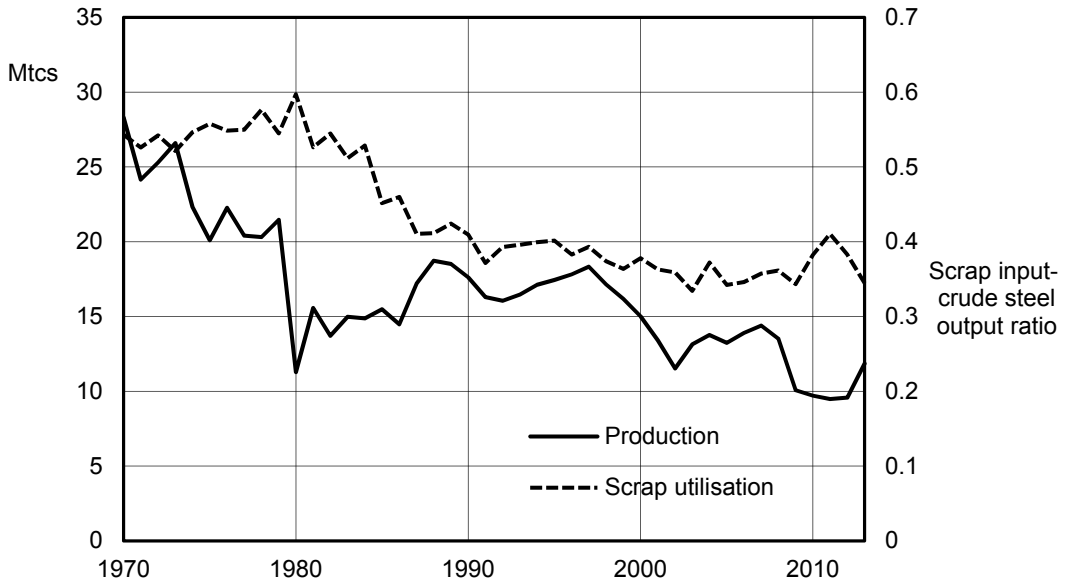

Figure 4-1: Crude steel production and scrap utilisation in the UK iron and steel sector, 1970-2013 (Hunt 2014, ISSB 2012a)

4.1.1 Sector structure

The conventional measure of production for the iron and steel industry is tonnes of crude steel (tcs). Crude steel is defined as the total of usable ingots, continuously cast semi-finished products (slabs, billets and blooms) and liquid steel for castings (ISSB 2012a). Figure 1 shows historic production of crude steel alongside scrap consumption as a proportion of crude steel production. Crude steel production peaked at 28Mt in 1970 and declined dramatically after the energy crises of 1973 and 1979. Production capacity underwent significant rationalisation after the second crisis and after a more gradual decline sector output in 2007 was half the output in 1970. The fuel price hike and recession of recent years led to a steep drop in production and the large blast furnace at Teesside was mothballed for over two years. However the drop in production was not accompanied by a drop in production capacity (15-16Mtcs) and production has seen a recovery in 2013 and 2014 (World Steel Association 2014b).

Production is based on the primary route, which manufactures new steel from iron ore, and the secondary route, which recycles steel by re-melting scrap. Ore-based steelmaking is spread over three integrated steelworks (Teesside works, Port Talbot, and Scunthorpe) of similar production capacity and scrap-based steelmaking is spread over four electric arc steelworks (Rotherham, Tremorfa, and two in Sheffield). Five companies share production from these seven sites (UK Steel 2014).

The energy intensity of primary manufacture is about four times higher than that of recycling and is restricted to the use of carbon intensive fuels. The structural balance between each route can therefore have a significant influence on the average energy and emissions intensity of the sector. A turning point in structural change was reached in 1980, before which recycling was increasing and after which recycling has been declining.

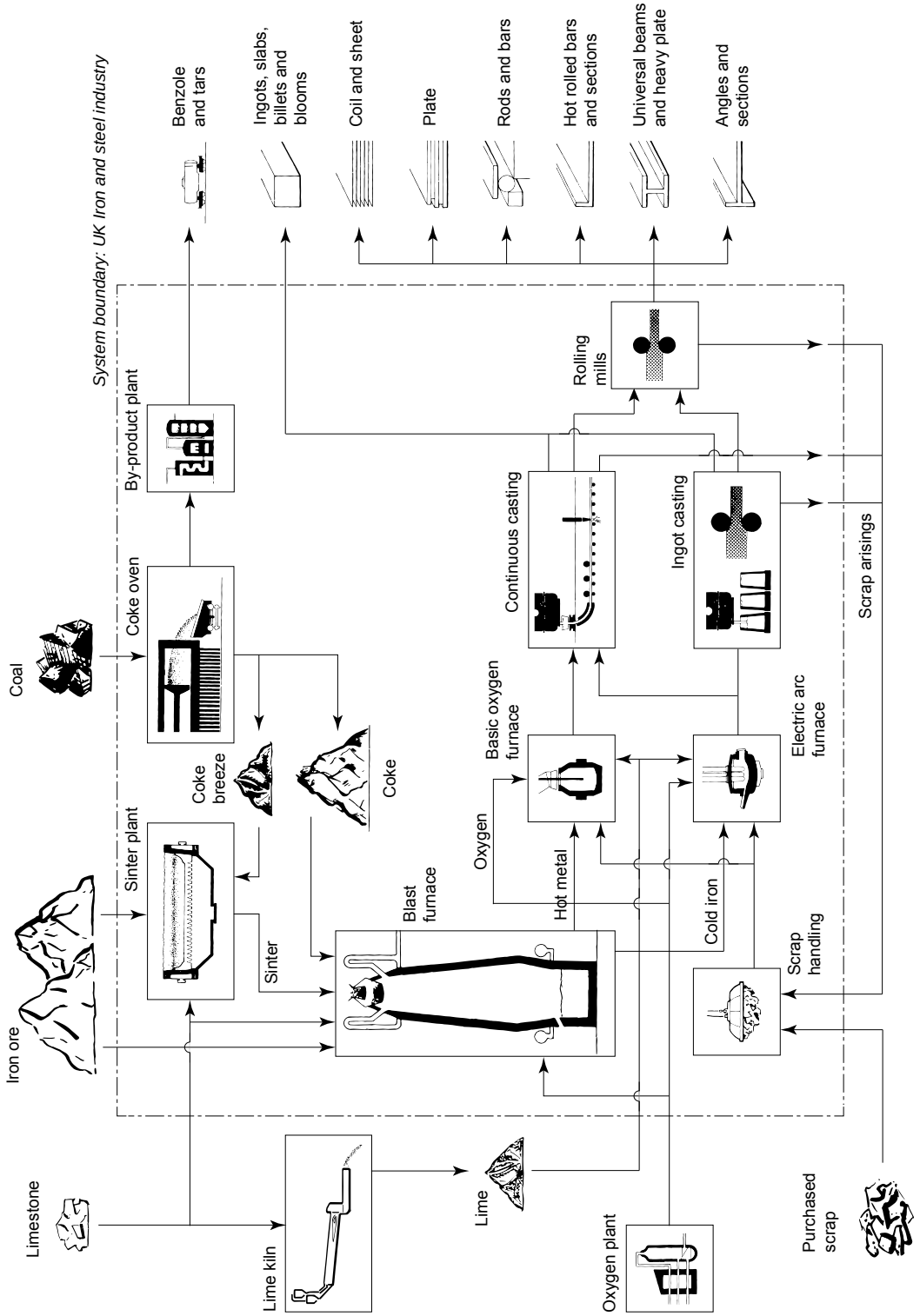

Figure 4-2: Simplified process flow diagram of the UK iron and steel sector, updated from Energy Audit Series (1982)

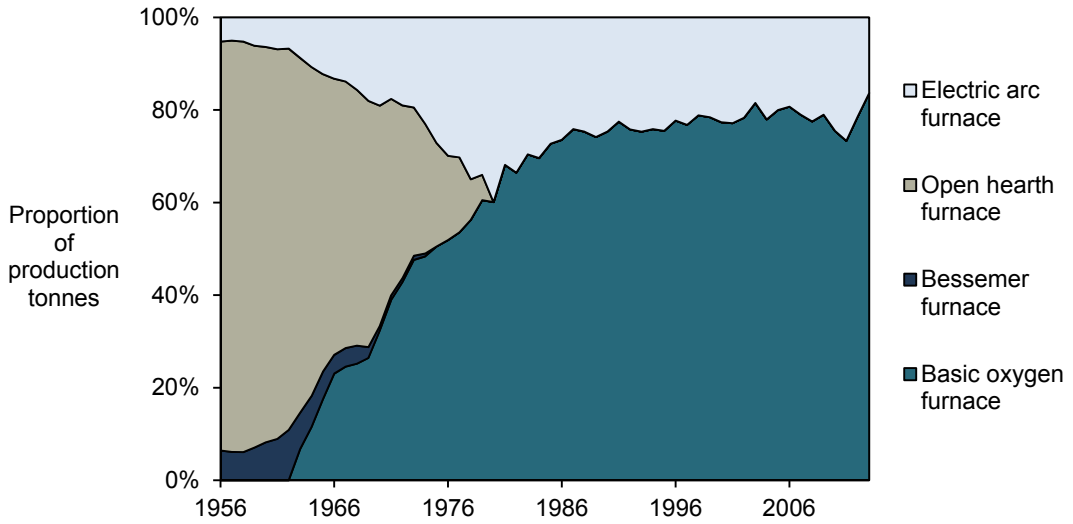

Figure 4-3: Proportion of crude steel production via UK steelmaking furnaces, 1956-2013 (Hunt 2014, ISSB 2012a)

Figure 4-1 is a simplified process flow diagram illustrating the production of steel through its key sub-processes and via both process routes. At the integrated steelworks large amounts of coal is fed into coke ovens and converted into coke. The bulk of this coke is charged to the blast furnace where it provides three roles: its combustion releases heat to raise the temperature of the furnace; its carbon content acts as a reducing agent to separate iron; and its mechanical properties give physical support to burden materials while being porous enough for hot gasses to permeate to the furnace top (Energy Audit Series 1982). Tar and benzole products are separated from the raw coke oven by-product gas to be sold.

Iron ore, coke breeze and limestone are charged to the sinter plant where they are roasted and agglomerated to form sinter. Sinter is the main form in which iron ore enters the blast furnace. The pig iron, or 'hot metal', from the blast furnace is charged with steel scrap (15% by weight) to the basic oxygen furnace (BOF) where a large amount of oxygen is blown in to remove excess carbon and produce liquid steel. Waste gasses from the coke oven, blast furnace and basic oxygen furnace are utilised as fuel elsewhere in the steelworks to heat processes directly and raise steam in boilers for process use and electricity generation.

Operating outside of the integrated steelworks is the electric arc furnace (EAF) into which scrap is charged with <5% cold iron. The main energy input to this process is electricity which is purchased from the national grid. Other steelmaking furnace types with different iron-scrap input shares have been used over the years that are now obsolete. Most notably, the basic open heath furnace (OHF) was ultimately phased out in 1979 owing to its inefficiency and high running costs compared with the newer BOF technology. Figure 4-3 illustrates this historical structural change by the relative production from different steelmaking furnaces. Note how specific scrap consumption in Figure 4-1 mirrors the EAF output trend from 1980.

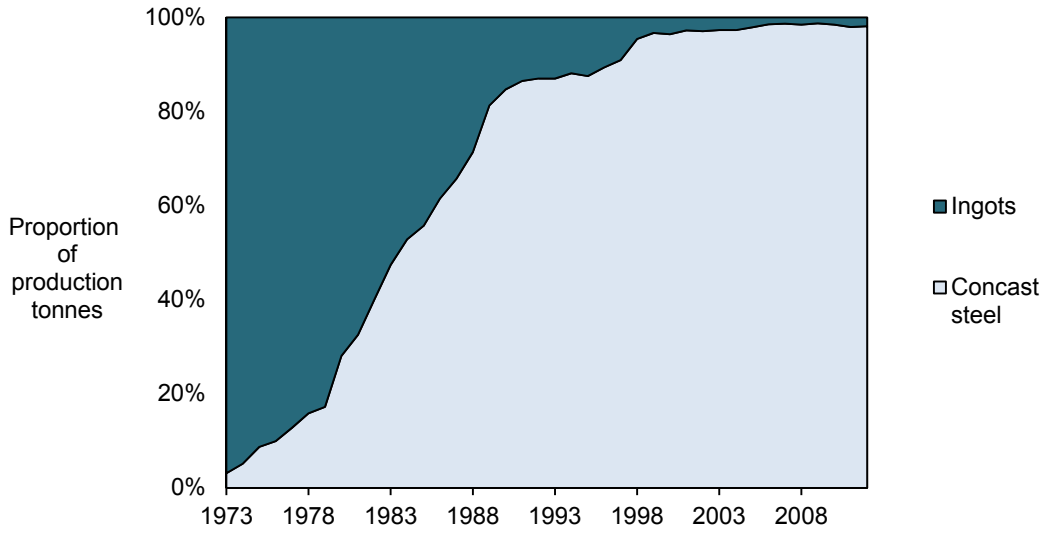

Figure 4-4: Proportion of UK crude steel production by casting method, 1973-2012 (Hunt 2014, ISSB 2012a)

Today liquid steel from the BOF and EAF is mostly continuously casted into slabs, billets and blooms. Otherwise it is cast into ingots which may be reheated and primary rolled to form steel at the semi-finished state. The need to reheat steel ingots before rolling makes this a less efficient casting route. Over the years the sector has phased out ingot casting except for low volume orders and special applications. This process change is displayed in Figure 4-4.

Semi-finished steel is allowed to solidify and cool before it is either reheated and fed into hot-rolling mills or exported oversees. The saleable finished steel product is a direct output of the hot-rolling mill or the output of a series of rolling, and possibly coating, operations.

Figure 4-5 shows the material flow of the sector in 2007. The industry ran at nearly full capacity producing 14.4Mtcs (~85% capacity utilisation). Of this about 3Mt was exported, 0.1Mt sold directly to home consumers and the remainder used as feedstock for hot-rolling. About 10.4Mt of hot-rolled steel was produced, just over a quarter of which was used as feedstock for further finishing. After cold rolling and other downstream mill losses, production approximates to 10Mt of ECSC[13] finished and end products. This figure was estimated with a weighted average rolling mill yield efficiency of ~92% which would equate to the amount of internally arisen scrap published by ISSB (2012a). Net home and export delivery of industry products, including slab, was 14.2Mt. This figure incorporates a small additional finishing yield loss due to the use of some ECSC products as feedstock to other industry products (including bright bars, cold rolled narrow strip, tubes and pipes), and would imply an import by the industry of about 1Mt of steel for conversion.

[13] ECSC products as defined for the common market of the European Coal and Steel Community, which was founded at the 1951 Treaty of Paris.

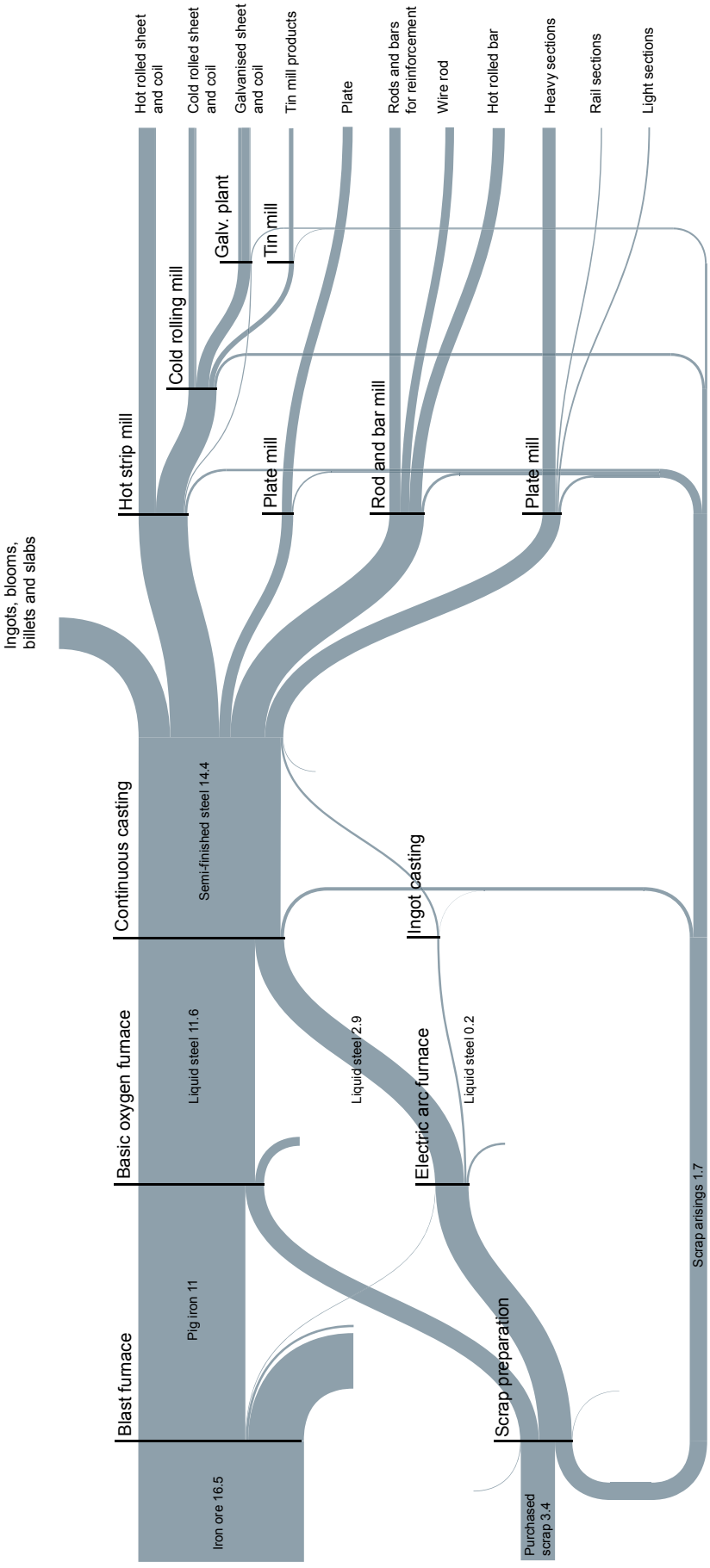

Figure 4-5: Sankey diagram of material flow in the UK iron and steel sector, 2007, derived from ISSB (2012a, 2013)

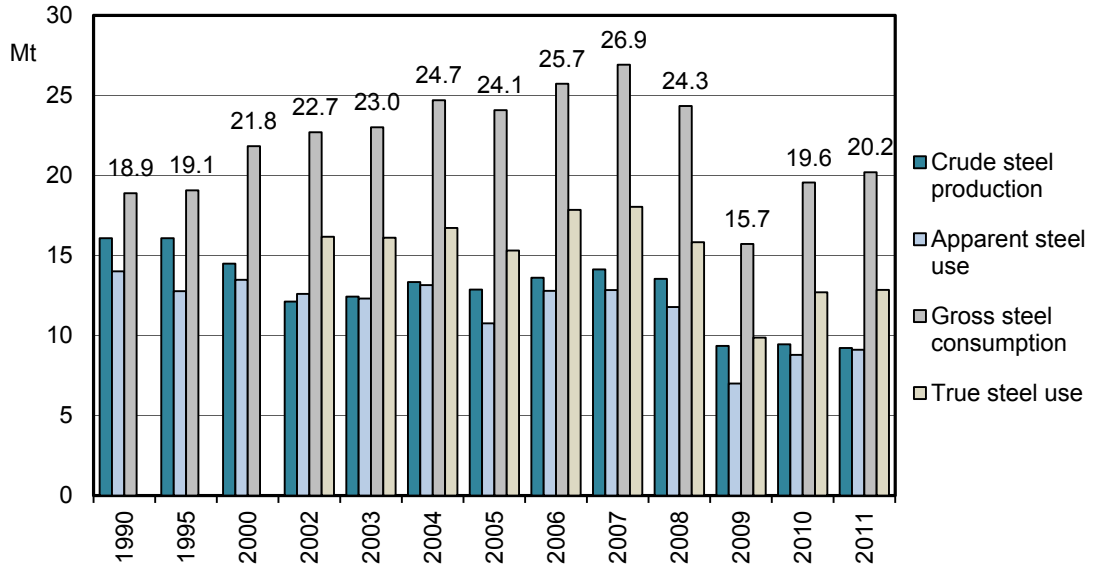

Figure 4-6: Steel production, apparent use and gross consumption 1990-2011, and true steel use 2002-2011 in the UK iron and steel sector
(ISSB 2012a, World Steel Association 2013)

4.1.2 Trade and consumption

Of the 14.2Mt of industry products delivered in 2007, 7.6Mt was exported and 6.5Mt was delivered to UK demand sectors, about half of which were stock merchants. Excluding material for conversion the UK imported 7.8Mt of steel industry products, equating to 14.3Mt of steel industry products delivered to the UK market.

Figure 4-6 shows the trend in steel production and consumption since 1990. Apparent steel use (net home disposal), which accounts for non-producer exports, was 12.8Mt of finished steel (Mtfs). Steel is also embedded in imported and exported consumer goods. The UK typically has the highest net import of steel goods of any country in Europe (World Steel Association 2013). The import and export of steel embedded in goods was 12Mt and 7Mt respectively, equating to a 'true steel use', of 18Mt (ibid.).

Gross steel consumption, or 'steel requirement' (UK Steel 2014) in 2007, which excludes the export of metal goods and non-producer derived finished industry products, was about 27Mt. This is a simple aggregation of industry products delivered to the UK market and steel embedded in imported goods. Assuming average yield losses for industry product forming and metal goods fabrication of 9% and 18% respectively (Allwood and Cullen 2012), gross consumption is 29Mtfs or 32Mtcs. By the same calculation, true steel use becomes 19Mtfs or 23Mtcs, an increase of some 60% on crude steel production.

Steel is evidently a highly tradable commodity. Indeed, importing steel directly into the UK would even reduce overall transport tonnage as the UK does not produce its supply of raw material feedstock. For every tonne of crude steel produced the UK imports about 1.7 tonnes of

iron ore and coal, the bulk of which comes from Australia and the Americas (ISSB 2012a). Conversely the UK exports double the amount of scrap feedstock, around 7Mt, than is purchased by the sector (ibid.).

According to the European Commission (Commission Decision 2010/2/EU), the EU basic iron and steel and coke oven products industries (SIC 24.1 and 19.1) are exposed to significant risk of carbon leakage. A sector may be designated this classification if its trade intensity[14] with countries outside of the EU is over 10% and costs (direct and indirect) relating to the EUETS is over 5% of production cost (measured as a proportion of gross value added). The classification is also given if either measure exceeds 30% (ibid.).

Trade intensity and cost incurred by the EUETS was calculated for the EU sector to be 32.3% and 10.6% respectively (Summerton 2010). This was later updated for the '2015-2019 carbon leakage list' to 25.1% and 22.2% respectively (European Commission 2014d). However an assessment for the Commission (ECORYS 2013) uncovered no evidence of carbon leakage since the launch of the EUETS in 2005, and attributed relocation of European steel production over the period since then to shifts in global demand and resource costs.

4.2 Sector baseline and historical assessment

This section presents a bottom-up energy and material baseline off of which improvement potential for energy demand and GhG emissions reduction can be measured. In constructing the baseline, past trends in resource use and emissions have also been assessed to inform for estimates of unknown plant efficiencies and provide context to the remaining improvement potential in the sector.

The base year for analysis is 2007 as this was the most recent year in which the sector operated at nearly full capacity and for which detailed data was available. Given its 'lumpy' structure, production this year provides a significantly closer representation of the sector's present structure of installed capacity. Some technological improvements since 2007 have been made and these were accounted for by incorporating them in an updated representation of the 2007 baseline.

The sector has been modelled over the period 1973-2011. Background data and analysis relating to the energy and emissions baseline may be found in sections A5.1, A5.4, A5.7, and A5.11 of the Appendix.

[14] Trade intensity is defined as the ratio of the sum of traded goods (value of exports + imports) and the total market supply (annual turnover + total imports).

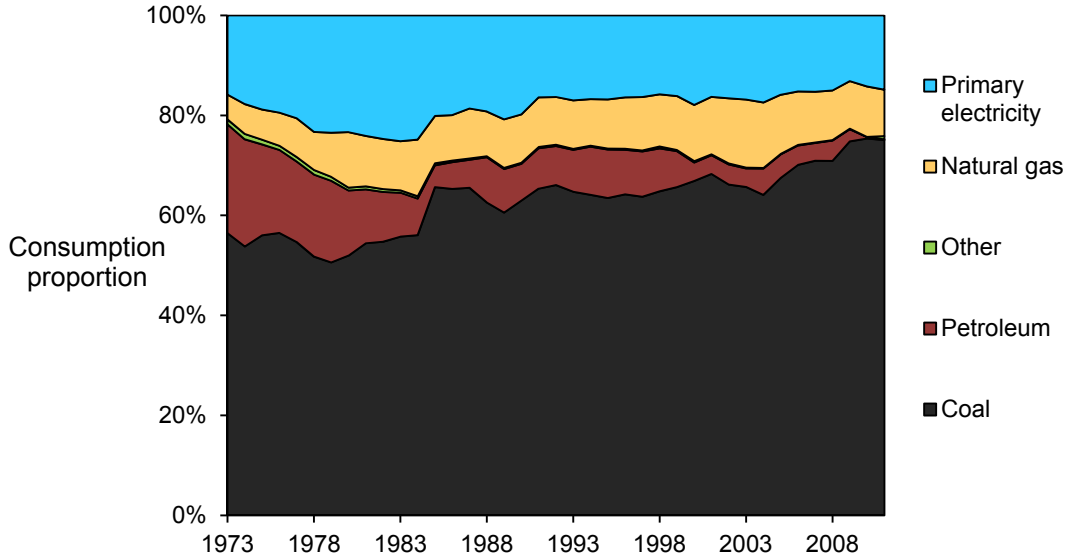

Figure 4-7 : Primary fuel and electricity split of the UK iron and steel sector, 1973-2011 (DECC 2013b, 2013c, ISSB 2012a)

4.2.1 Sector

Energy demand and GhG emissions in the sector principally result from a large consumption of coal. Remaining energy demand is dominated by natural gas and electricity. Figure 4-7 displays the energy split for sector simple primary energy[15] since 1973. As a proportion of total fuel intake coal consumption has increased as has natural gas. Petroleum has progressively been substituted and no longer plays a significant role in the sector. Reduction in the proportion of primary electricity demand has resulted from efficiency gains at external power stations (DECC 2013b, 2013c) and a relative decline in steel production via the EAF.

About half of the energy demand at the process plant level is energy transformed, or manufactured, from the demand for primary fuels. Figure 4-8 is a Sankey diagram illustrating fuel, steam and electrical energy flows of the sector in 2007 at process plant level. Most of the coal is converted to coke by the coke ovens for use in the blast furnace and sinter plant. The industry produces coke at a slight deficit to blast furnace requirements and so some is purchased. Other manufactured fuels include coke oven gas (COG), blast furnace gas (BFG) and basic oxygen furnace gas (BOFG) which are process by-products of the plant from which they are named. These gasses are combusted to supply process heat or to raise steam in boilers. The steam is used at the process plant or in turbine generators for electricity production. Natural gas is used to supplement the by-product gasses at processes or as the single process fuel input, particularly for processes situated outside integrated steelworks sites. A small amount of fuel oil and gas oil is used for minor ancillary processes. In 2007 a significant amount of fuel oil was consumed as blast furnace injectant but has since been substituted by coal.

[15] The net manufactured fuel is excluded here.

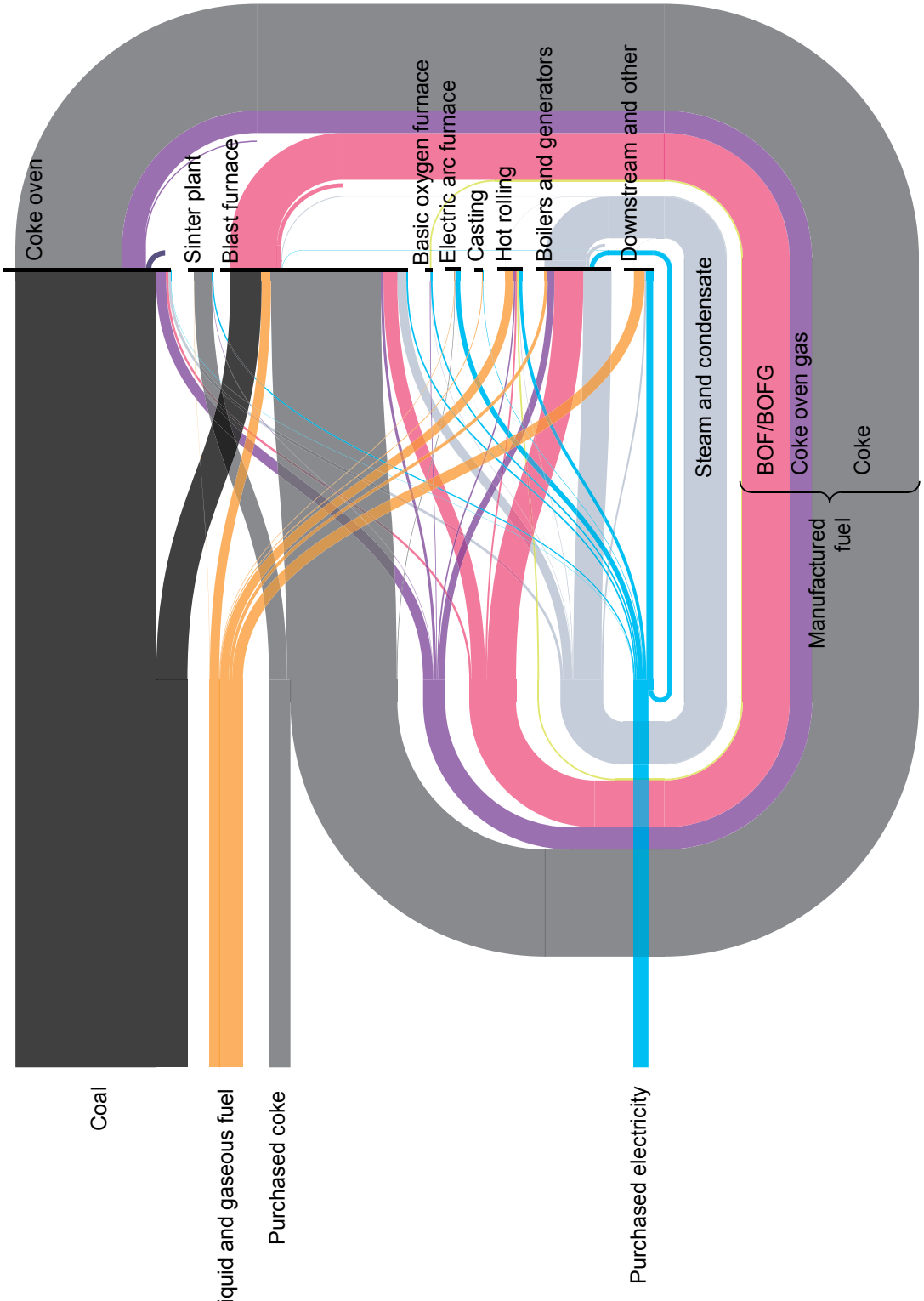

Figure 4-8: Sankey diagram of plant-level fuel, steam and electricity flows in the UK iron and steel sector in 2007

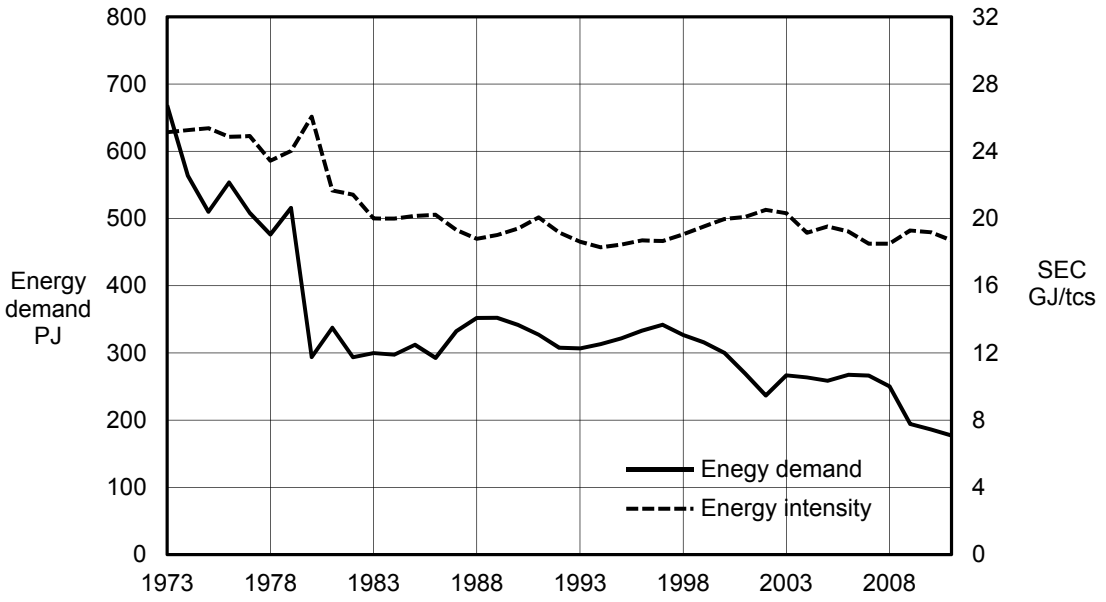

Figure 4-9: Net energy demand and intensity of the UK iron and steel sector, 1973-2011 (ISSB 2012a)

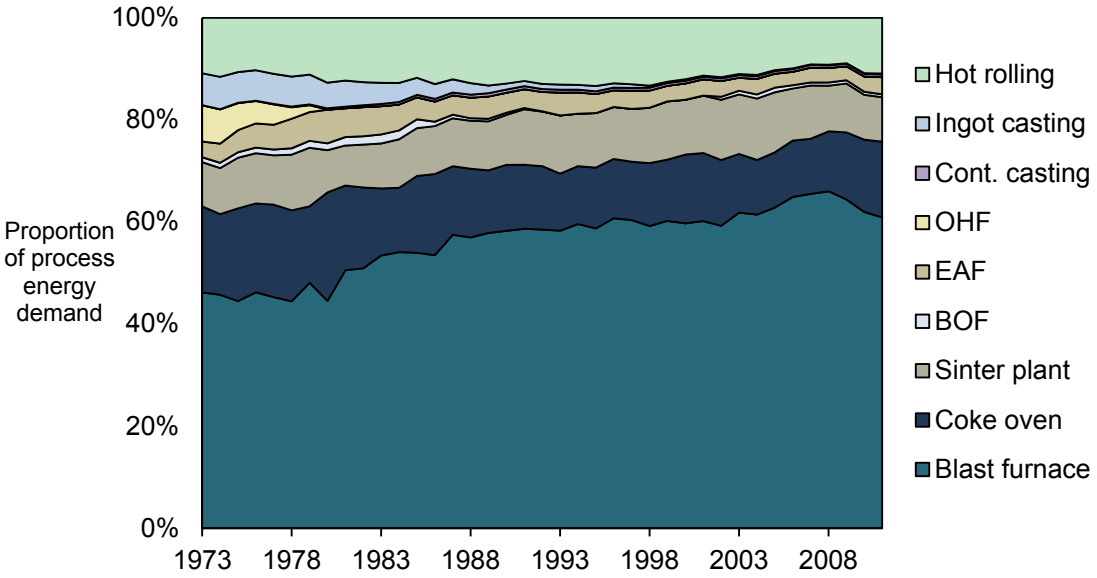

Figure 4-10: Proportion of energy demand by process in the UK iron and steel sector, 1973-2011

Historical net energy demand and intensity (SEC) trends are displayed in Figure 4-9 on an energy supplied basis. The sharp reduction in energy demand in 1980 is linked to the contraction in output (see Figure 4-1). Production was especially low that year because of strike action. The accompanying spike in energy intensity resulted from the need to keep some furnaces hot and other general effects of operating plant at low capacity (Langley 1984b). Energy intensity then fell to a much lower level owing to deep structural rationalisation. Energy intensity continued to fall over the 1980s before stagnating. Energy demand, however, reduces gradually from the 1990s.

In 2007 about 80% of net sector energy was demanded by the following processes:

- Blast furnace, including stoves and blowers (53%)
- Coke oven (9%)
- Sinter plant (8%)
- Hot rolling mill, including reheat furnace (7%)
- Electric arc furnace, including secondary metallurgy (2.5%)
- Basic oxygen furnace, including secondary metallurgy (0.5%)
- Casting, including continuous casting machine and ingot casting soaking pit with primary mill (0.4%)

The remaining 20% is dominated by boilers and power generation plant, and finishing processes downstream of hot-rolling such as cold rolling and coating operations. Ironmaking (coke oven, sinter plant and blast furnace) accounts for 70% of sector energy demand.

Figure 4-10 shows historical changes in the proportions of net energy demand shared by the above processes. After 1980 blast furnace energy demand has increased proportionally as iron production relative to steel production has increased. This structural change has been largely offset by the phasing out of the open hearth furnace, the ingot casting route, and reductions in coke production for ironmaking. The recent dip in blast furnace energy is a result of the large blast furnace at Teesside being mothballed. However this was temporary and the relative energy demands of before will have since returned.

4.2.2 Key processes

In this section the technical status of each major process stage is examined in detail. For detailed descriptions of processes the reader is referred to the European Commission's Integrated Pollution Prevention and Control (IPPC) Best Available Techniques (BAT) Reference Document for the iron and steel industry (European Commission 2012b) and the Environment Agency's IPPC sector guidance note (Environment Agency 2004).

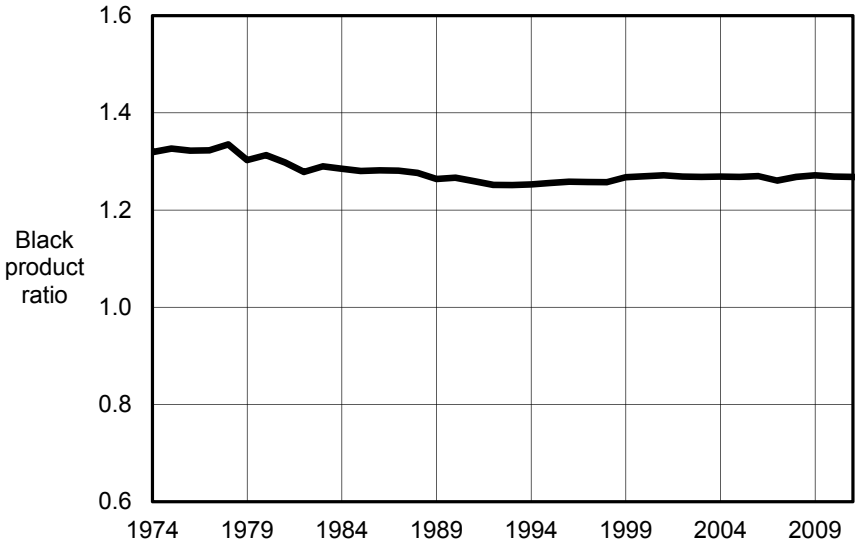

Figure 4-11 : Coke oven black product ratio[16] in the UK iron and steel sector, 1974-2011 (ISSB 2012a)

4.2.2.1 Coke oven

Coal softens at high temperatures which would reduce burden permeability in the blast furnace and lower blast furnace efficiency (IISI 1998). The coking process removes volatile substances from coal producing carbonised lumps with appropriate physical and chemical characteristics for efficient blast furnace operation. Metallurgical coke has three functions in the blast furnace: a fuel providing heat for reaction, a reducing agent for the formation of pig iron, and a material providing physical support to the burden material while allowing hot gasses to permeate upward. Coke oven output is measured in tonnes of dry coke (tdc).

Almost all coke production in the UK is metallurgical coke produced by the iron and steel industry. The sector operates 12 by-product recovery coke oven batteries at five coke oven plants and an average of 42 ovens per battery (Environment Agency 2004). The ovens are contiguously arranged such that the combustion gasses of intervening flues heat adjacent ovens. Bituminous coal, or coking coal, is blended and prepared for charging to the batteries, though no special drying treatment is applied and the coal is charged with a moisture content of about 10% (Lewis, B., TATA Steel, pers. corr., April 2014). The coke leaving the ovens is rapidly cooled at wet coke quenching stations to minimise oxidation. By-product coke oven gas is processed through product recovery plant to separate tar and benzole which is further treated before sale.

Figure 4-11 shows the 'black product ratio' of sector coke production since 1973. The black product ratio is the dry weight ratio of coal input to coke output and provides a good indicator for efficiency improvement. It is difficult to accurately calculate total SEC of coke ovens as the

[16] Ratio before 1990 is estimated as being pro-rata with wet basis.

transfer of energy through them is considerably large compared with process energy loss. Thus a small error in coal or coke CV would yield significant error in net energy demand. Determining reliable CVs would necessitate a detailed study with information on the type and mix of coking coals and in-situ measurements of all mass flows at frequent time intervals. Process energy, i.e. the energy that heats and drives the process, is a more appropriate scope for assessing efficiency (IISI 1998). The key process energy demands include:

- Coke oven gas and blast furnace gas demand for oven underfiring
- Steam demand for by-product processing and operation of the exhauster
- Electricity demand for pumps, motors and other ancillary equipment

As indicated in Figure 4-11, coke oven efficiency improved mainly over the 1980s before levelling off. Coke production has undergone significant rationalisation over the years with average production rising from 145 to 355 kt per battery between 1978 and the most recent battery closure in 2002. This would suggest replacement of smaller, less efficient plant over the period. It is also the case that operators will have sourced more consistent quality coals over time responding to environmental legislation on SO_2 emission and the need to reduce costs by maximising productivity from existing capital stock (Lewis, B., TATA Steel, pers. corr., April 2014). An example of specific equipment improvements were those applied to the 84 oven, twin battery plant at Morfa, Port Talbot, after its rebuild in 2005. These included the installation of variable speed drives to reduce electricity demand and other equipment replacements to reduce coke oven gas demand for underfiring (Duffy et al. 2008)

Evidently the improvements have been incremental and no major plant modification, such as waste heat recovery, has yet been undertaken. A planning application was approved in 2004 to construct a new 160 oven, twin battery coking plant with heat and power recovery situated at the other Port Talbot coking site, Grange, which ceased operation in 2001 (Neath Council 2004). However, the project did not go ahead and Port Talbot continues to produce coke at a deficit to blast furnace requirement with the difference made up by imports. Most of the coke ovens operated at Scunthorpe and Teesside are at least 30 years old (Environment Agency 2004), indicating opportunity for deploying major refurbishment or replacement technologies in the short-medium term.

4.2.2.2 Sinter plant

The sinter plant agglomerates iron ore and other feedstock materials into a clinker-like aggregate with improved permeability, homogeneity and reducibility for efficient blast furnace operation (Environment Agency 2004). Iron ore fines are first mixed with recycled materials from downstream processes (blast furnace dust and sludge, BOF slag and mill scales) for their iron content. Flux material such as limestone and dolomite is also added here to reduce the energy requirement for calcination in the blast furnace. Coke breeze (small-grade coke) is added to the

sinter bed to assist in the ignition of the charge (ibid.). The coke breeze used in the process is mostly rescreened from direct coke production onsite (DECC 2013a). In 2007 sinter constituted about 70% of the weight of iron bearing burden in the blast furnace (Leach 2013). Output from the sinter plant is measured in tonnes of sinter (ts).

The UK operates four sinter strands with an average grate area of around 320m^2 per tonne of sinter (Environment Agency 2004). As is conventional in Europe, all strands are down-draft travelling grates. As the grate moves, fans draw large amounts of air over the ignited sinter feed to ensure the coke breeze ignites evenly. Volatile metal dusts are driven off and the feed composition fuses to form the aggregate, which is then fed through a cooler. Oversized sinter agglomerate is crushed while undersized sinter is recycled back through the process. Key process energy demands include:

- Coke breeze providing thermal energy in the sinter bed
- A small amount of coke oven gas, supplemented with natural gas, used as ignition fuel
- Electricity demand for the large sintering fan, the cooling fan and other ancillary processes

Sinter strand no.5 at Port Talbot was recently modernised with a capacity increase, an overhaul of the cooling system, a new automation system, and a new drum for mixing and granulation (Siemens VAI 2011b). No major efficiency technologies, such as waste heat recovery, have yet been deployed in the UK.

4.2.2.3 Blast furnace

The role of the blast furnace is to provide the right conditions for the use of carbon in the reduction of iron oxide (Michaelis et al. 1998). Most of the carbon and iron oxide enters the furnace in the form of coke and sinter respectively. The product of the blast furnace is molten pig iron, or 'hot metal', which is subsequently converted into liquid steel via the basic oxygen furnace. The process of melting and separating metal from its ore is known as smelting. Output from the blast furnace is measured in tonnes of hot metal (thm).

The UK operates 7 blast furnaces with a combined capacity of about 12.7Mthm per annum[17] (Dryden 2004, Environment Agency 2004, Maddocks et al. 2012b). The blast furnace is a tall vertical shaft furnace consisting of a crucible shaped hearth at the furnace bottom, an intermediate zone known as the bosh, and a stack (or shaft) leading from the bosh to the furnace top (Environment Agency 2004). The system described by the blast furnace typically encompasses ancillary plant and equipment including hot stoves, blowers and by-product gas cleaning equipment.

[17] Increased from around 12.1Mthm in 2007.

Coke, sinter, iron ore lump, pellets and limestone are charged continuously through a double valve system at the furnace top. Pressurised and heated air, 'hot blast', is blown through water cooled nozzles, 'tuyères', just above the hearth. The blast air is enriched with oxygen to reduce energy losses from the heating of nitrogen inside the furnace. Auxiliary fuel is also injected with the hot blast and partly substitutes the coke input. The coke and fuel injectants combust in the presence of air simultaneously releasing thermal energy and reducing gasses. The gases flow counter-current to falling iron bearing materials and convert iron oxide into iron. The thermal energy is sufficient for the iron to melt and limestone to undergo calcination into lime which, along with direct additions of lime and lime carried in sinter, absorbs sulphur and other iron ore impurities to form slag. The molten iron and slag percolate through unburned coke and accumulate in the hearth to be tapped from the furnace periodically. The slag is granulated for sale as additions to cement and concrete.

Steam is also injected with the blast air producing further reducing gasses via the 'water-gas shift' reaction with the fuel (Michaelis et al. 1998). Both calcination and the water-gas shift reaction are endothermic so the blast air is preheated to compensate for this while ensuring the right temperatures are maintained inside the furnace. The stoves are fuelled mainly by the gas leaving the furnace top, blast furnace gas, which has an NCV of about 3.2MJ/Nm^3 owing to incomplete reaction of reducing gasses. About a quarter of the blast furnace gas produced is used to fuel the stoves where it is enriched with smaller amounts of coke oven gas and natural gas. Large turbines, called blowers, powered by steam or electricity increase the blast air pressure ensuring that gasses are able to permeate through the burden (IISI 1998). In summary, the key areas of process energy demand are:

- Coke charge and coal injection to the blast furnace
- Blast furnace gas, coke oven gas and natural gas fuelling the blast furnace stoves
- Electricity and steam powering the blowers and other ancillary equipment

Coke charge and coal injection account for the blast furnace 'fuel rate'. Figure 4-12 shows the change in blast furnace fuel rate since 1955. As with the coke oven, blast furnace efficiency appears to have shown past improvement before levelling off from around 1990. Fuel switching has occurred with increasing levels of injection. Fuel oil injection was introduced first but ceased for a time in the early 1980's due to high oil prices. The sector investigated coal injection technology and by the time oil prices had reduced and oil injectors were re-commissioned, the first granulated coal injectors had been installed. Coal injection has since steadily increased over fuel injection and now all UK blast furnaces operate coal injection technology. A pulverised coal injection unit capable of an injection rate of up to 235kg/thm replaced fuel injection at the No.1 furnace at Teesside in 2012 (Siemens VAI 2012).

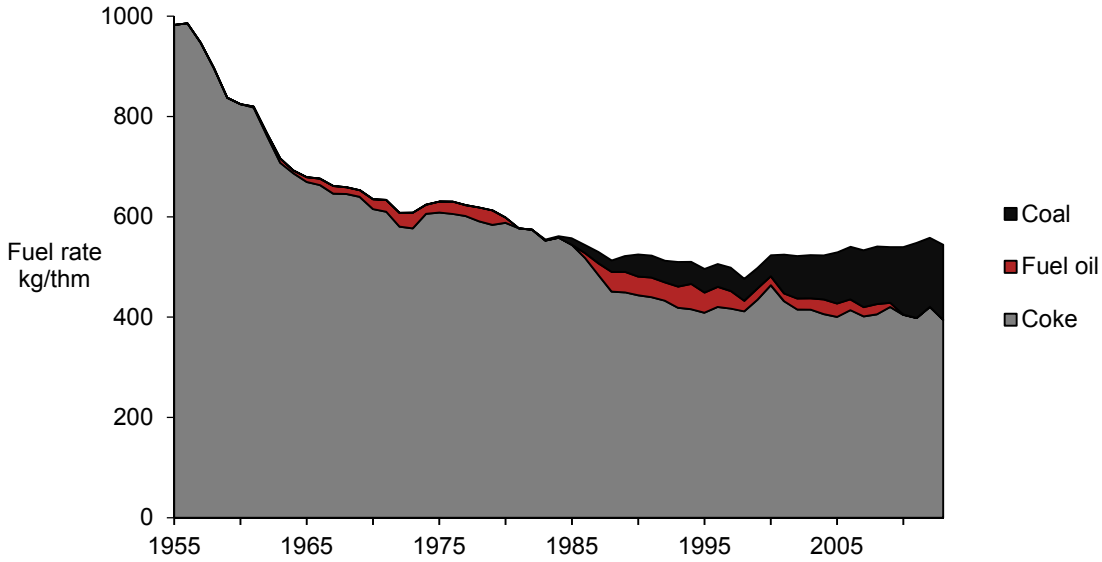

Figure 4-12: Blast furnace fuel rate in the UK iron and steel sector, 1955-2013 (DECC 2014c, 2014d, 2014e, IISI 1990, 1996, ISSB 2012a)

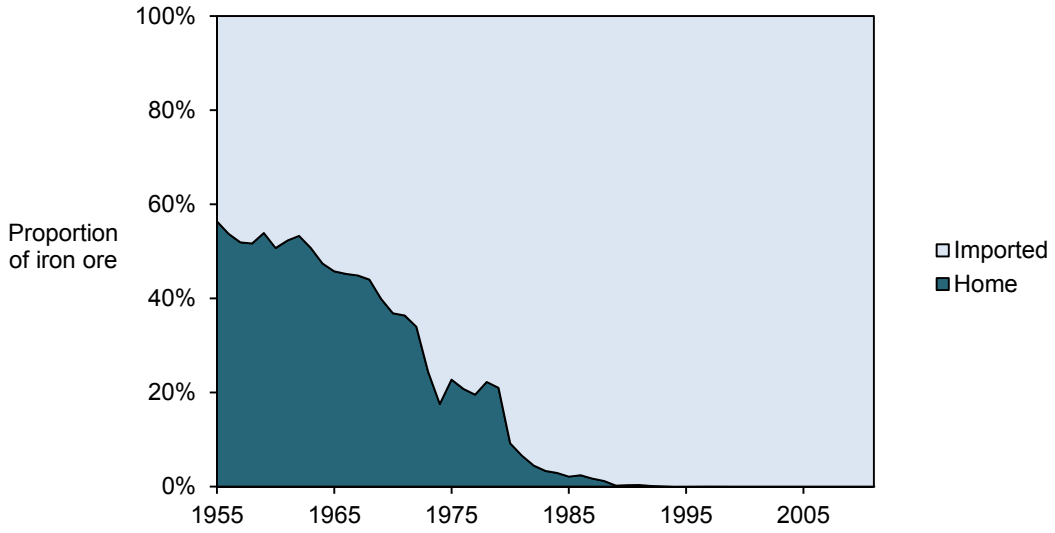

Figure 4-13: Proportion of home and imported ore consumption in UK blast furnaces, 1955-2011 (ISSB 2012a)

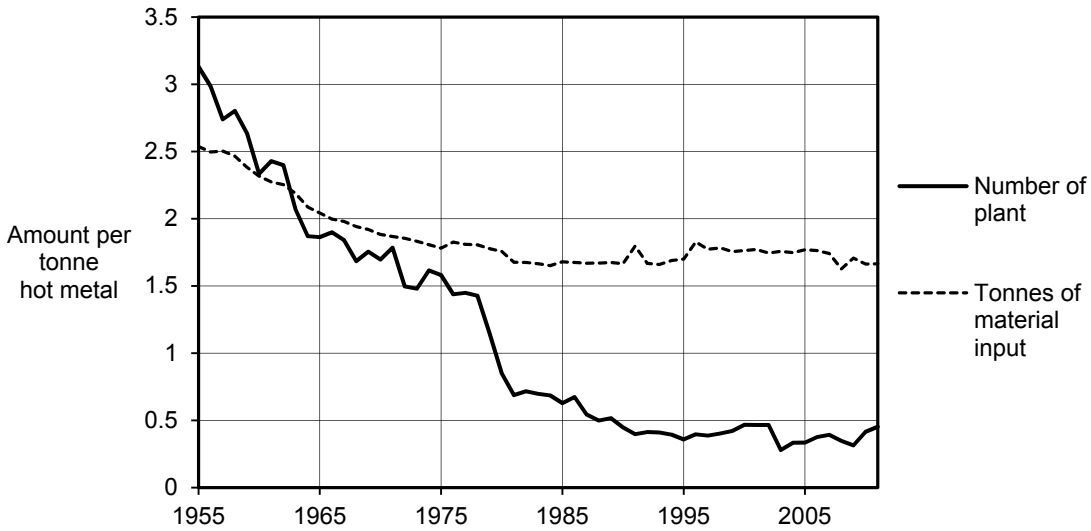

Figure 4-14: UK blast furnace material and plant intensity, 1955-2011 (ISSB 2012a, Leach 2013)

It is generally more economically attractive to inject coal as higher injection rates may be achieved leading to further reductions in coke oven requirement. The maximum injection rate possible may be around 250kg/thm or about half the total fuel rate (Ghosh and Chatterjee 2008). In 2013, injection rate was 150kg/thm, or 28% of total fuel rate, indicating that there is room left for improvement (DECC 2014b).

In energy terms the replacement ratio between coke and coal is about 1:1 (IISI 1998). However, higher injection rates necessitate higher oxygen enrichment to maintain flame temperature, which would in turn lead to higher electricity demand for oxygen production outside of the sector. This increase is likely to be negated by higher blast furnace gas credit, lower blast air compression, and lower stove heating requirement (ibid.). The net energy demand change would be small and difficult to measure without detailed technical data and accurate fuel CVs.

Much of the improvement before 1980 can be attributed to a switch to high quality foreign ores with up to three times the iron content of UK based ore (Energy Audit Series 1982). Figure 4-13 shows historical reduction in the proportion of home ore consumption by the industry. Figure 4-14 shows historical change in blast furnace material input and plant intensity. Further reduction in blast furnace material throughput came about from a significant reduction in the consumption of limestone and metal scrap over the same period. Reductions in the consumption of other Fe bearing materials such as slags and scales have also been made since 1980 (ISSB 2012a, Leach 2013). In addition to these changes, significant plant rationalisation has occurred with the average yearly number of operating blast furnaces per output halving over the period 1955-79 and halving again over the restructuring of 1979-81, before reducing gradually over the subsequent decade.

If the top gas pressure leaving the furnace is over 1.5 bar gauge then energy may be recovered by passing the gas through an expansion turbine (IISI 1998). A top pressure recovery turbine (TRT) was installed at the Teesside No.1 furnace in the early 1990s producing an estimated 35kWh/thm (126 MJ/thm) of electricity (IISI 1996). It is technically feasible to equip the No.4 and No.5 blast furnaces at Port Talbot with TRTs. Port Talbot furnace No.4 was rebuilt in 2012 with a capacity increase, new control system, gas cleaning plant, more efficient stoves, variable speed drives and a planned campaign life of 15 years (Maddocks et al. 2012a). However it was not yet deemed necessary to apply heat recovery at the stoves and a TRT was considered economically unviable. Installing TRT on No.5 would be even less viable owing to its smaller size.

4.2.2.4 Basic oxygen furnace

Hot metal and scrap is converted to liquid steel at the basic oxygen furnace (BOF) via the application of pure oxygen which oxidises and removes carbon. The amount of scrap making up the metallic charge can be as high as 35% (Barker et al. 1998, Langley 1984b). As is most common in Europe (European Commission 2012b), the UK operates Linz and Donowitz (LD)

BOF vessels with bottom stirring (Brämming 2010, Normanton 1986). Seven vessels with a combined capacity equivalent to about 13.3Mtcs per annum are operated at the three integrated steelworks (Environment Agency 2004, TATA 2011). Output from the BOF is measured in tonnes of liquid steel (tls).

The BOF is a large open topped steel vessel lined with basic refractories and mounted in a trunnion ring assembly (Environment Agency 2004). Prior to entering the BOF, hot metal leaving the blast furnace undergoes desulphurisation via deep injection of reactants in the transfer ladle. Scrap is charged to the BOF, making up around 15% of the gross metallic charge, before the hot metal is poured in. Lime and calcined dolomite are also added to aid in the removal impurities. Oxygen is blown on to the surface of the hot metal at supersonic velocity through a water cooled top-lance while inert gasses are injected through bottom tuyères to aid homogenisation. The oxidisation reaction is highly exothermic raising the temperature of the product and releasing a hot off-gas (BOFG) rich in carbon monoxide. Some of the sensible energy of the BOFG may be recovered and the gas itself, having NCV of about 8MJ/Nm^3, can be cleaned and collected for use elsewhere in the steelworks as fuel. The liquid steel is tapped from the BOF and undergoes secondary metallurgical treatment including the addition of alloying elements such as ferro-manganese. Ladle treatment involves either a vacuum degassing system, ladle arc furnace unit or a combination of the two (ibid.). Some of the process slags are recycled in upstream processes for their iron content.

The BOF itself requires no fuel input as sufficient thermal and chemical energy is carried in by the hot-metal. Electricity is required for the production of oxygen but as oxygen is bought in by the industry this energy is not counted as a direct input to the sector. Process energy requirement of the system is therefore low and is made up of the following:

- Coke oven gas for ladle preheating
- Electricity for mechanical power, e.g. cooling pumps, lance operation and furnace tilting

The key to maximising energy utilisation at the BOF is in capturing the sensible and chemical energy of the BOFG. The UK began capturing BOFG in the mid-1980s and in 1994 average capture from the UK BOF plant was 0.3GJ/tls (IISI 1996). At that time steel production was split between four integrated steelworks with the Llanwern steelworks accounting for 20% of liquid steel capacity and capturing BOFG at a rate of 0.55GJ/tls (Michaelis 1998). Its closure in early 2002 would therefore have equated to a reduction in sector BOFG capture to around 0.2GJ/tls.

In 2010 a new BOF gas and heat recovery scheme was commissioned at Port Talbot (TATA 2011). With the site representing about 40% of integrated steelmaking capacity in 2007 and capturing at a rate of around 0.5GJ/tls, as implied by its consumption in 2011 (Maddocks et al.

2012b), average sector capture is assumed to have increased to 0.35GJ/tls. Port Talbot also recovers the sensible heat in the BOFG to raise wet steam which is fed through a superheater fuelled by blast furnace gas, which would otherwise be flared, and supplemented with natural gas. The superheated steam enters a steam generator to produce about 10% of site electricity demand, equating to an estimated 0.07GJ/tls on an energy supplied basis. A generator conversion efficiency of about 40% corresponds with the BAT standard for sensible heat recovery which is 0.17GJ/tls (IISI 1998). Despite the progress made from this project, however, further capture of BOFG and related sensible heat is technically possible in the sector.

4.2.2.5 Electric arc furnace

The purpose of the electric arc furnace (EAF) is to recycle ferrous metal back through the steelmaking system by melting steel scrap. The UK operates four EAFs at four sites with a combined capacity equivalent to 3Mtcs per annum[18].

Scrap and <5% cold iron make up the metallic charge and are loaded into baskets along with fluxes (lime and calcined dolomite). Lump coal or coke is also loaded to promote slag formation and allow for higher arc voltages. The furnace roof is closed and carbon electrodes are lowered near to the charge. An electric arc is struck between the electrodes liberating most of the thermal energy required to melt the charge. The electrodes are consumed by the process at a rate of about 2.2 kg/tls (Entec UK Ltd. 2006b) and release carbon dioxide. Further heat is provided by the combustion of natural gas and exothermic reaction of other carbon sources, including the charge, with injected oxygen. Liquid metal is tapped from the furnace and, as with BOF steelmaking, ladle furnaces and vacuum degassers are used for secondary metallurgy of liquid steel prior to casting.

Regarding energy, the coal or coke input is treated as a process feedstock and the energy demand for oxygen production is external to the industry. The key areas of process energy demand are therefore:

- Electricity for charge melting, secondary metallurgy and other ancillary equipment
- Natural gas injection into the furnace
- Steam for process equipment heating and vacuum degassing (Entec UK Ltd. 2006b)

EAF BAT technology has shown continual improvement over the last half century. Specific electricity demand of BAT has more than halved from 630kWh/tls (2.3GJ/tls) in 1965 to 280kWh/tls (1GJ/tls) today (De Beer et al. 1998a, Siemens VAI 2011a). Between 1978 and 1994, electricity demand from UK EAF plant reduced from 570 to 490kWh/tls (Energy Audit

[18] This figure is lower than production in 2007 due to the closure of about 1Mtcs of capacity at Thamesteel in Sheerness and Alphasteel in Newport.

Series 1982, IISI 1996), or about half the BAT rate of reduction. In the time since a number of smaller furnaces have closed and liquid steel production has rationalised from 230 to 500ktcs per plant over the period 1996-2013 (Environment Agency 2004, ISSB 2012a). Furthermore, old capacity was replaced in 2006 by a new 1.2Mtcs EAF at Tremorfa. As a result of these changes, it is likely that further improvement in the average electrical efficiency of UK EAF plant has been made since 1994.

In 2004 none of the EAFs still in operation today used a scrap preheating system (Environment Agency 2004) and no such investment has been stated by the manufacturers in the time since. Without this measure in place it is assumed that average electrical efficiency has improved with the same rate as over the period 1978-1994. This approximates to 425kWh/tls (1.5GJ/tls) in 2007.

4.2.2.6 Casting

Continuous casting prepares liquid steel into solid, semi-finished shapes (slabs, billets and blooms) to be hot rolled. Traditionally steel would be solidified into ingots before being reheating in soaking pits and primary rolled into the semi-finished equivalent. Additional fuel requirement is necessary for reheating the ingot and average process yield losses are closer to 10%, though can be as low as 5% (Tomlinson, M., Sheffield Forgemasters, pers. corr., May 2014). Casting in the UK is nearly all continuous with only a small amount of ingot casting remaining for large forgings or small orders of special steel product.

In the continuous casting process, liquid steel is fed from the secondary metallurgy ladle to the preheated 'tundish' of the continuous casting, 'concast', machine (Environment Agency 2004). The liquid steel passes into a water cooled copper mould with a cross-section defining the semi-finished form. As the outer skin solidifies the steel is drawn through and cooled with water sprays before discharging onto rollers, some of which are electrically driven. The steel is cut to the appropriate length with torch cutters (ibid.). Only a very small amount of fuel and electricity is required by the plant and a yield loss of 2-3% can be expected (IISI 1998).

Each casting method will have improved incrementally over time with investment in new plant but with little consequence to sector energy demand. Rather, improvement has resulted from the switch between methods. Output from each route is measured in tonnes of semi-finished steel (tsfs).

4.2.2.7 Hot rolling

The hot rolling process reheats semi-finished steel for it to be further rolled into 'hot-rolled steel'. Accordingly, mill output is measured in tonnes of hot-rolled steel (thrs). Hot-rolled steel is a

saleable finished steel product of the industry or a feedstock for cold rolling and coating processes before sale.

A number of hot rolling mill types operate in the UK producing strip, plate, rod, bar and section. Each type has slightly different energy and yield efficiency so the efficiency of hot-rolling would represent the average of mills weighted by mill output. Common to hot rolling mills is the reheating furnace, which heats the semi-finished steel to the desired temperature for rolling. In the UK, average fuel requirement for reheating furnaces comprises of natural gas with smaller amounts of COG, BFG and BOFG (DECC 2011a). Once heated the steel is formed via a series of electrically driven rolls.

The last time reheating and rolling was openly surveyed in the UK was in 1978 (Energy Audit Series 1982). Subsequent improvements were made over the 1980s through the dissemination of recuperative furnace technology (Lees and Brown 1989). Over the past decade best practice furnace technology has been installed at Port Talbot (Corus 2006) and high efficiency combustion burners have been installed at Llanwern (TATA 2008). Some waste heat is recovered to produce steam (Leach 2013) and the sector average amounts to around half of the BAT level indicated in literature (IISI 1998).

Additional energy reductions at the furnace can be achieved by 'hot-charging' the semi-finished steel. The amount saved depends on the temperature of the hot charge and the proportion of charge heated. Hot bloom charging at Rotherham and Scunthorpe was reported in 2001 saving a third of heating energy in each case (European Commission 2001). The utilisation of this method is limited at Port Talbot as some 40% of slab is despatched to Llanwern before rolling (Dryden 2004). The method is inapplicable to the Teesside steelworks as the slab produced there is exported.

Given the recent investment in improved technology and practices, an approximation of 1.5GJ/thrs for average reheating furnace fuel efficiency is considered reasonable.

4.2.2.1 Boilers and power plant

There appears to be no published literature relating to the efficiency of technology for steam and electricity generation in the sector. However it is reasonable to model the integrated steelworks system on the conventional boiler plant and generator system defined in IISI (1998) (Leach, D., ISSB, pers. corr., June 2013). To estimate the efficiency of the system, data on sector fuel demand for autogeneration and heat generation in the DUKES (DECC 2014b) was combined with data gathered for steam production and use (Leach 2013).

BFG, COG and natural gas is combusted at onsite boilers to raise steam. Based on fuel (NCV) input per net of steam and condensate output, the boilers have about 80% efficiency. Some of the

steam produced at the integrated site is used to supply process heat demand and some is used for electricity generation. Electricity is generated in a condensing turbine and back-pressure, or 'topping', turbine. Steam at high pressure is fed into the back-pressure turbine where it is converted into low-pressure steam. The energy absorbed by the turbine is converted to electricity with an assumed efficiency of 95% (IISI 1998). Based on the gathered data this equates to a production of about 0.75PJ of electricity in 2007. Total sector generation that year was 5.7PJ which leaves 4.6PJ of condenser turbine electricity after accounting for back-pressure turbine and TRT electricity. Based on the net steam input and condensate output, the condenser turbine has a generation efficiency of about 30%. For comparison, the boiler and condenser turbine efficiency defined by IISI (1998) is 86% and 36% respectively. Based on the above calculations, overall efficiency of electricity generation from the UK system is around 25%.

4.2.3 The manufacturing site

Most activity in the sector occurs at either an integrated steelworks site or an EAF steelworks site. Therefore the 2007 sector baseline has been split into these two sites. The integrated site is then divided into: coke oven, sinter plant, blast furnace, basic oxygen furnace, continuous casting, hot rolling, boiler plant, power generation plant (conventional condenser turbine and back-pressure turbine configuration), downstream and other. The EAF site is divided into: electric arc furnace, continuous casting, ingot casting, boiler plant, downstream and other. The category 'downstream and other' is the energy demand remaining from the sector after all other processes. Process outputs and resource flows for each site of the baseline can be seen from Table A-62 in section A5.11.2 of the Appendix.

The sum of energy demand at each site amounts to the total energy demanded by the sector[19]. In reality not all hot rolling and other downstream finishing operations occur at the site of steel production, e.g. Llanwern strip mill. The dislocation of part of the process chain limits how much of it can utilise upstream process heat and by-product gasses. This is taken into account in later analysis by capping the amount of by-product gas used for downstream and other to 75% of fuel demand.

The amount of hot-rolled steel produced at the integrated steelworks site is calculated as the remainder from total hot-rolled steel after applying its yield efficiency (~92%) to the production of semi-finished steel at the EAF site. As expected this remainder (7.7Mt) is significantly lower than total integrated site semi-finished steel production (11.4Mt) owing to the export of slab from Teesside. As such, semi-finished steel or crude steel are more appropriate output indicators for site production than is hot-rolled steel.

[19] A very small amount of energy which is attributed to a site with an electric induction furnace is not included in the split for simplicity and as its impact on the sector is almost negligible.

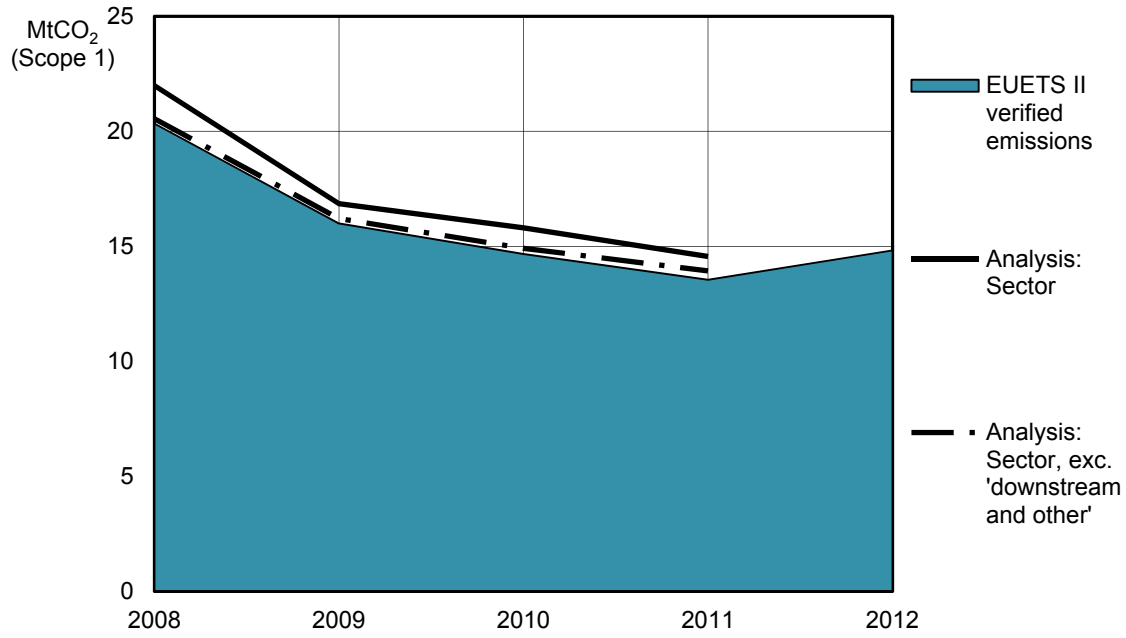

Figure 4-15: Comparison of calculated CO_2 emissions with emissions verified for trading under phase II of the EUETS for UK iron and steel sector (Environment Agency 2013)

Regarding ECSC products, operations downstream of hot-rolling have been identified as applying exclusively to sheet or strip (Leach 2013). About 2.4Mt of hot rolled sheet is cold rolled and of this about 1.7Mt is put through a coating operation, 0.4Mt of which is secondary coated. All sheet and strip is produced between Port Talbot and Llanwern (Environment Agency 2004) and these operations have been allocated to the integrated site. However, finishing operations involving other industry products, beyond ECSC, would not be exclusive to the integrated site. These considerations are accounted for in the split of category 'downstream and other' between the sites but may be treated as indicative as further study of these operations is outside the scope of the present work.

4.2.3.1 EUETS installations

The EUETS covers direct CO_2 emission from priority installations within the sector. Figure 4-15 compares calculated CO_2 emission from the sector with that verified for trading under phase II of the scheme. Sector emissions are shown with and without activities categorised under 'downstream and other'. With these activities excluded there is good correspondence with verified emissions. Leaving the total as it is, verified emissions represent around 93% of direct sector CO_2 emissions and 90% of direct sector GhG emissions.

4.2.4 Steelmaking

The steelmaking system is a process chain, or web, constituting the identified process plant. The exact definition of the system is chosen based on the analysis objective. First it is necessary to determine the steelmaking product. For steelmaking the choice of product may be described by levels, where each level is differentiated by a single stage in the process chain. The levels identified as appropriate in representing sector process energy are: liquid steel, semi-finished steel and hot-rolled steel. Note that crude steel is not considered a level of steelmaking because it is an aggregation of steel products (semis and ingots) of different stages in the steelmaking process. Continuously cast slab, billet and bloom are types of semi-finished steel whereas ingots require primary rolling and incur yield losses before this level.

As steelmaking describes a process chain, the output of a given process is constrained by its use as an input elsewhere in the system. In contradistinction to this, the 'iron and steel sector' describes a system in which the total outputs of all processes are counted regardless of their destination. The process outputs of the sector may be stocked, sold, discarded, or used while inputs may be drawn from stock or purchased if not directly received from another process. To reconcile sector and steelmaking systems it is useful to create a process input/output matrix as shown for 2007 in Table 4-1. In that year the blast furnace consumed 12.4Mts and produced 10.96Mthm, so the blast furnace input/output ratio is 12.4/10.96=1.131. To construct the steelmaking system, start with the amount of system product and multiply up the steelmaking levels to build the system.

Note that consumption of total as well as sector produced coke is included in Table 4-1 because a significant amount of coke is imported into the sector. Using the former incorporates the production of coke from outside of the UK. If the efficiency of UK coke ovens is applied to this production then the technical efficiency of UK based process plant at producing steel with a balanced coke production may be calculated. This measure is useful when comparing between different countries but should be avoided when accounting for energy use and efficiency opportunities specific to a country.

Input / Output	CO_{Total}	CO_{UK}	SP	BF	BOF	EAF
SP	0.045	0.045				
BF	0.384	0.315	1.131			
BOF				0.916		
EAF				0.016		
CC					0.821	0.204
IC						1.111

Table 4-1: Process input/output matrix of the UK iron and steel sector in 2007 (ISSB 2012a, Leach 2013)

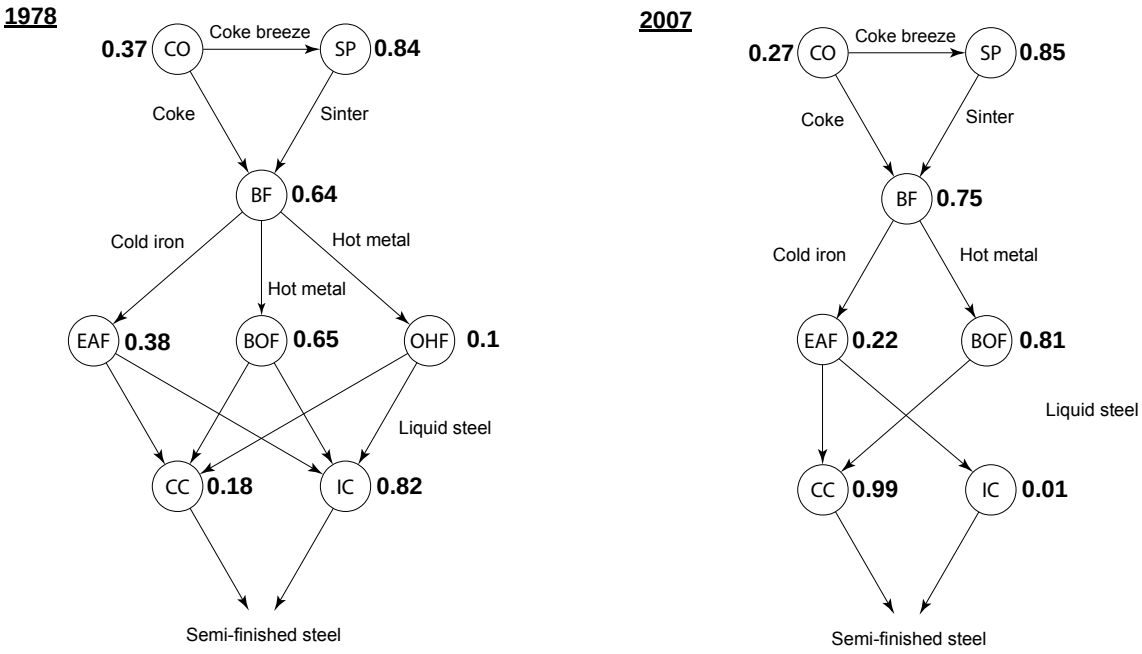

Figure 4-16: UK semi-finished steelmaking system structure in 1978 and 2007

Figure 4-16 displays process flow diagrams of the UK semi-finished steelmaking systems of 1978 and 2007. Included is the coke oven (CO), the sinter plant (SP), the blast furnace (BF), the basic oxygen furnace, the electric arc furnace, the open hearth furnace, continuous casting (CC), and ingot casting (IC). As can be observed from comparing the two structures, the amount of iron produced for steelmaking has increased significantly. Despite this, coke production has contracted owing to greater substitution from blast furnace injectant and a higher proportion of coke import. Sinter production for steelmaking has increased only marginally due to an increased use of iron ore lump and pellets in the blast furnace. The BOF/EAF share increased significantly over the period and the OHF was phased out (in 1979). Improvements in yield efficiency from steel furnaces and casting have also been made.

4.2.5 Steelmaking route

The steelmaking system may be divided into separate routes to the system product. Table 4-2 lists process outputs in both systems. The ore-based, primary steelmaking route is described as the BF-BOF route and the scrap-based, secondary steelmaking route as the BF-EAF route. Though no EAF in the UK is co-located with a blast furnace, the plants are associated through the consumption in the EAF of a small amount of purchased iron.

Figure 4-17 is a diagrammatic representation of the steelmaking routes at the level of liquid steel (LS) and semi-finished steel (SFS). From LS level to SFS level the number of routes doubles from three to six as the output of any steel furnace may be consumed in either of the two semi-finishing processes.

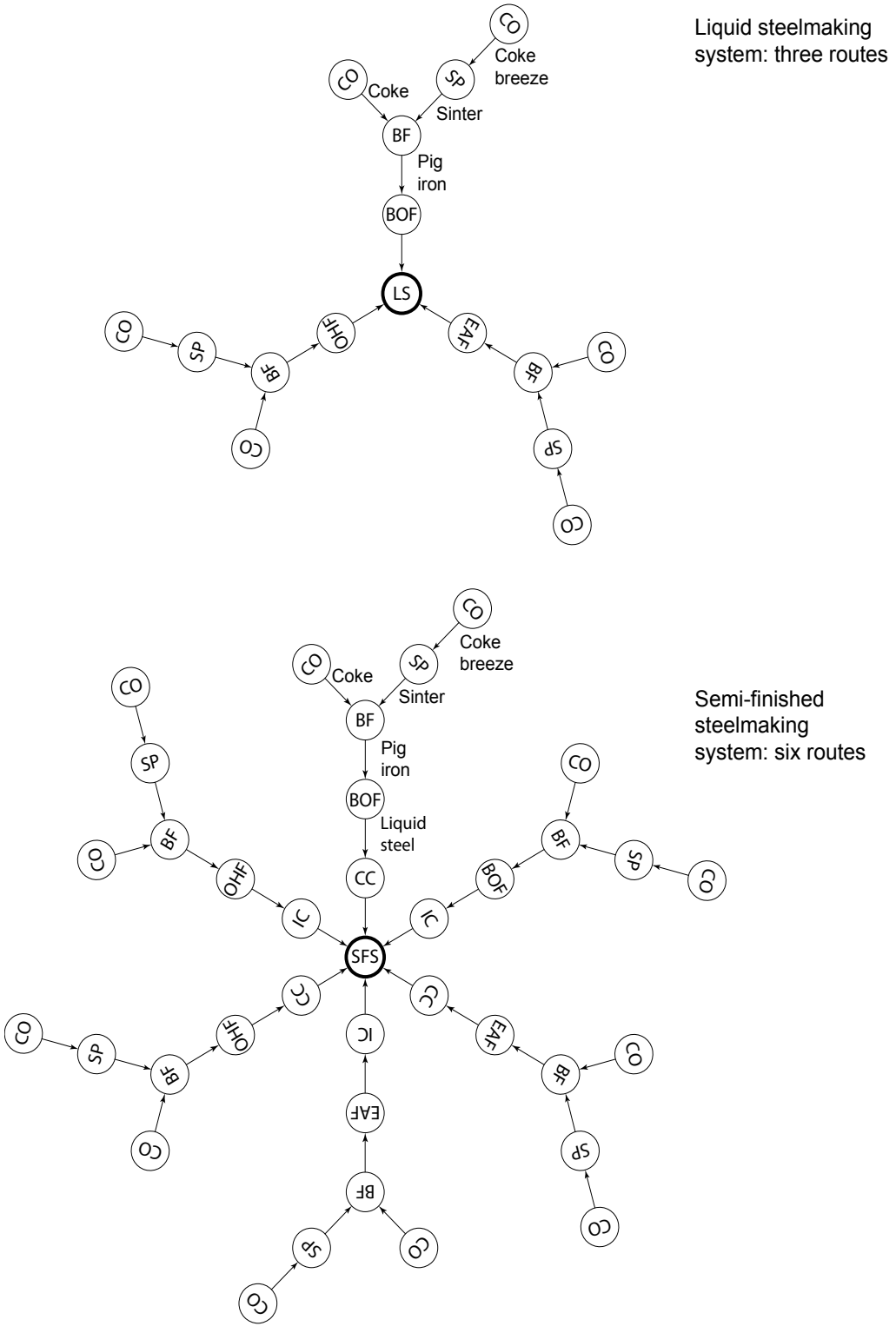

Figure 4-17: Diagrammatic representation of past and present UK steelmaking systems and routes

Process/system (output)	Iron and steel sector[20]	Steelmaking[21]		
		All routes	BF-BOF	BF-EAF
Coke oven (dry coke)	4,077	3,927	3,908	18
Sinter plant (sinter)	13,851	12,138	12,081	57
Blast furnace (pig iron)	10,960	10,728	10,678	50
BOF (liquid steel)	11,653	11,653	11,653	-
EAF (liquid steel)	3,100	3,089	-	3,089
CC (semi-finished steel)	14,188	14,188	11,362	2,827
IC (semi-finished steel)	171	171	0	171
System (semi-finished steel)	14,359	14,359	11,362	2,998

Table 4-2: System and process outputs of the UK iron and steel sector in 2007 up to the level of semi-finished steel (ISSB 2012a, Leach 2013)

4.2.6 Decomposition analysis

The relative output from each route defines the system structure. Analysing route energy efficiency over time enables for the effect of structural change on system energy demand to be measured. The contributory effects of historical changes in system energy intensity, structure and output may be separated using the LMDI I decomposition method.

Figure 4-18 shows the results of applying this method over the period 1973-2011 to four systems: UK liquid steelmaking process (A), balanced UK liquid steelmaking process (B), balanced UK semi-finished steelmaking process (C), balanced hot-rolled steelmaking process (D). Where 'balanced' refers to an equalised coke production and consumption, as opposed to the real system in the UK in which there is typically a coke production deficit.

Generally the graphs show that energy demand change has been most sensitive to changes in steel production. Before 1980 the energy intensity effect stays fairly constant while the structural effect has a downward trend. This is because of an increase in production from the BF-EAF route relative to BF-BOF and BF-OHF routes. During this period scrap consumption per tonne of steel produced was increasing as the sector was becoming less dependent on ironmaking. Post-1980 the trend in structural effect reverses and the net intensity effect reduces energy demand until the 1990's where it levels off but for an increase from the late 1990's.

[20] EAF liquid steel production includes liquid steel for steel castings, SFS from the ingot route is estimated from an ingot production of 190kt; sector crude steel production is 14,390kt from these two routes.

[21] Coke deficit in the sector is maintained and all production is assumed to be consumed at the blast furnace with no exports or change in inventories, leaving the deficit amount to be met by imports only.

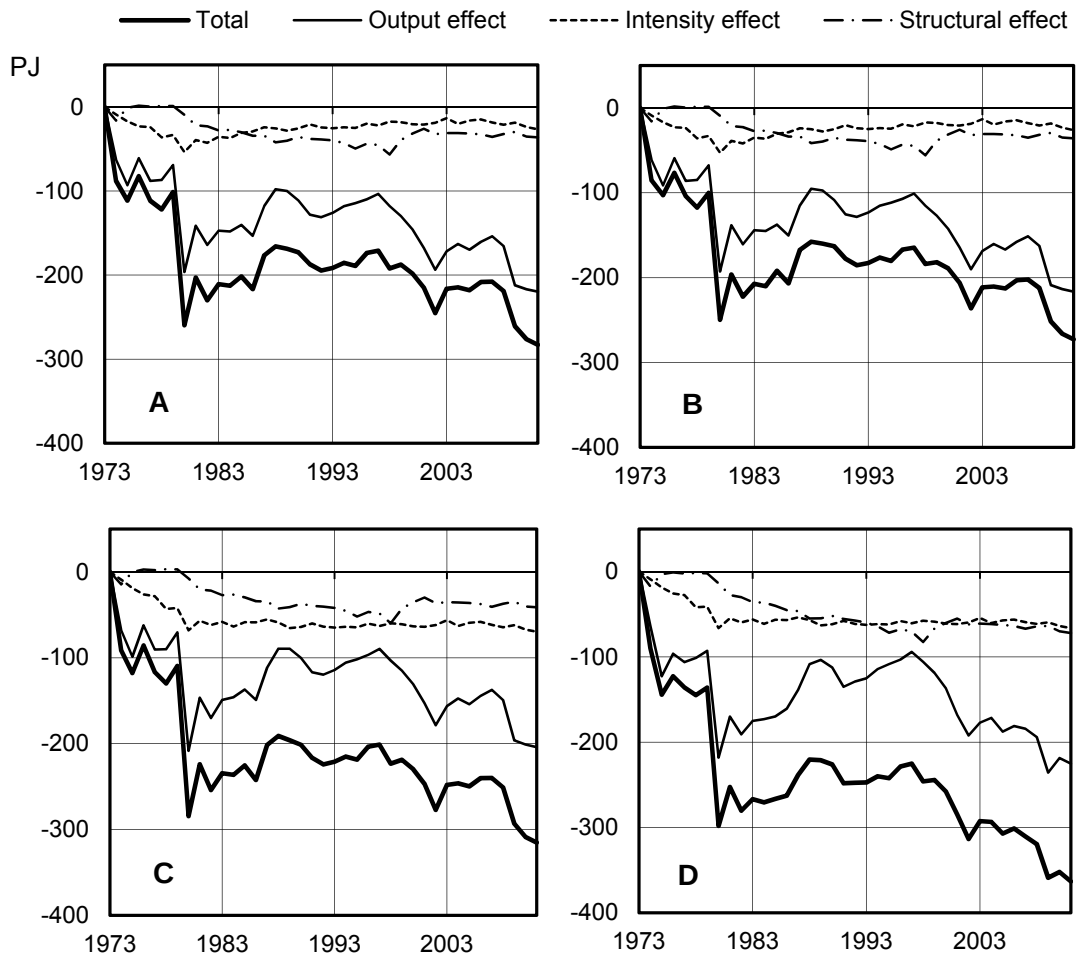

Figure 4-18 : Energy demand decomposition over 1973-2011 into output, structural and intensity effects for systems: UK liquid steelmaking process (A), balanced UK liquid steelmaking process (B), balanced UK semi-finished steelmaking process (C), balanced hot-rolled steelmaking process (D)

The similarity between graph A and graph B indicates that the general deficit in coke production is insignificant with respect to the long-term trend in sector energy demand. The difference in structural effect between graph B and C shows how a relative move towards the BF-BOF route is somewhat compensated for by the switch from ingot to continuous casting. The intensity effect is increased between graph C and graph D because of improvements to hot-rolling efficiency.

It should be noted that the energy intensity of the steelmaking route is dependant not only on the efficiency of its constituent processes, but on the specific consumption of iron. For example, iron input to the BOF can be displaced by increasing the proportion of scrap consumed to a limit of 35% the metallic charge. Over the study period this proportion reduced from 25% to 15% (ISSB 2012a, Leach 2013). Another, less significant, structural effect beneath the route level is the amount of sinter displaced by iron ore lump and pellet imports. The change from these sub-route structural effects is included with process efficiency improvements in contributing to the route intensity effect.

Figure 4-19: Greenhouse gas emissions decomposition into output, structural, intensity, fuel switching, and grid emissions factor effects for the balanced UK liquid steelmaking system

Figure 4-19 shows the decomposition of effects contributing to the emission of greenhouse gasses by the balanced UK liquid steelmaking system. The simple IDA method previously used by the DTI (1994) was used here because the LMDI I method for emissions change cannot be applied when the structural element has negative fuel consumption, i.e. processes that produce fuels (Ang 2005). The output effect is sector energy demand moving pro-rata with total sector output, the structural effect is the difference between the output effect and the summation of output effects at the subsector level, and the intensity effect is the remaining energy demand. The effect of fuel switching and grid emissions factor is the difference made to total energy demand when these variables are fixed.

It is not possible to meaningfully assess emissions trends at the process or steelmaking level without adjusting for changes in the wider sector. In particular, the utilisation of blast furnace gas at the integrated steelworks can have a dramatic effect on the emissions intensity of individual processes. This is because BFG has a low CV relative to carbon content, making it at least five times more carbon intensive as an energy source than either natural gas or coke oven gas. However, increasing the utilisation of BFG at a process makes sense at the site level if it would otherwise be flared. A multitude of other factors may also result in a switch of BFG between processes while maintaining the same overall utilisation onsite. To eliminate this 'noise' the overall ratio of BFG, COG, and natural gas demand at the integrated site is applied at the process level.

Fuel switching and cleaner external electricity generation have not had a significant overall effect on sector GhG emissions. This is unsurprising considering the dominance of coal or coal-based fuel consumption and the sector's dependence on it as a chemical reducing agent. Steelmaking energy intensity appears to be the more dominant effect on emissions reduction up to the late

1990's after which output declines and the intensity effect increases. Reduced efficiency at the integrated site is one side effect of operating plant at below capacity levels or having to acclimatise to a changing demand for steel. The issue is amplified with production spread across fewer plant than in the earlier past.

Figure 4-20 and Figure 4-21 are waterfall charts depicting the decomposition of semi-finished and hot-rolled steelmaking, respectively, in terms of both simple primary energy demand and GhG emissions. The period 1978-2007 is compared with the period of 1990-2007 for energy. Expressing decomposition in this way enables the impact of steelmaking to be set in the context of the overall sector, and allows for a clearer representation structural and intensity effects at multiple levels.

A greater rate of energy demand increase from liquid steelmaking structural change and decrease from switching casting route occurred over the 1980s. After this period these effects and the effect of energy intensity reduction at the level of semi-finished steel slowed significantly. Reduction in the intensity effect of hot-rolling is more consistent between periods however. With regard to semi-finished steelmaking energy, the structural effects in both periods have been of a similar magnitude to the intensity effects. Intensity effects become more dominant after the inclusion of improvements to hot-rolling.

Fuel switching has had a negative impact on emissions reduction. The effect of resource efficient fuel switching will increase emissions if flared blast furnace gas is better utilised as a substitute for natural gas. Greater reductions in electricity demand relative to natural gas in the BF-EAF steelmaking route would have had the opposite effect. Ultimately the use of fuels in the sector is highly integrated and process specific, and is better viewed as an incidental effect of changes in other areas.

It can be seen that the impact on the sector of steelmaking processes is far lower in terms of emissions than in terms of energy demand. This is because much of the emission deriving from carbon contained in coke and coal consumed by the blast furnace is deferred to other processes, mostly to steam and electricity production, via the combustion of blast furnace gas. Remaining sector emission reduces by two thirds over the period 1978-2007, and a third in the period 1990-2007. In 1978 the sector encompassed a wider collection of activities including a higher production from electric induction furnaces and production of liquid steel for steel castings. A higher production of iron surplus to its consumption in steelmaking also occurred in 1978. Additional improvements may be assumed from changes in general housekeeping and management systems and increases in energy and yield efficiencies of downstream processing.

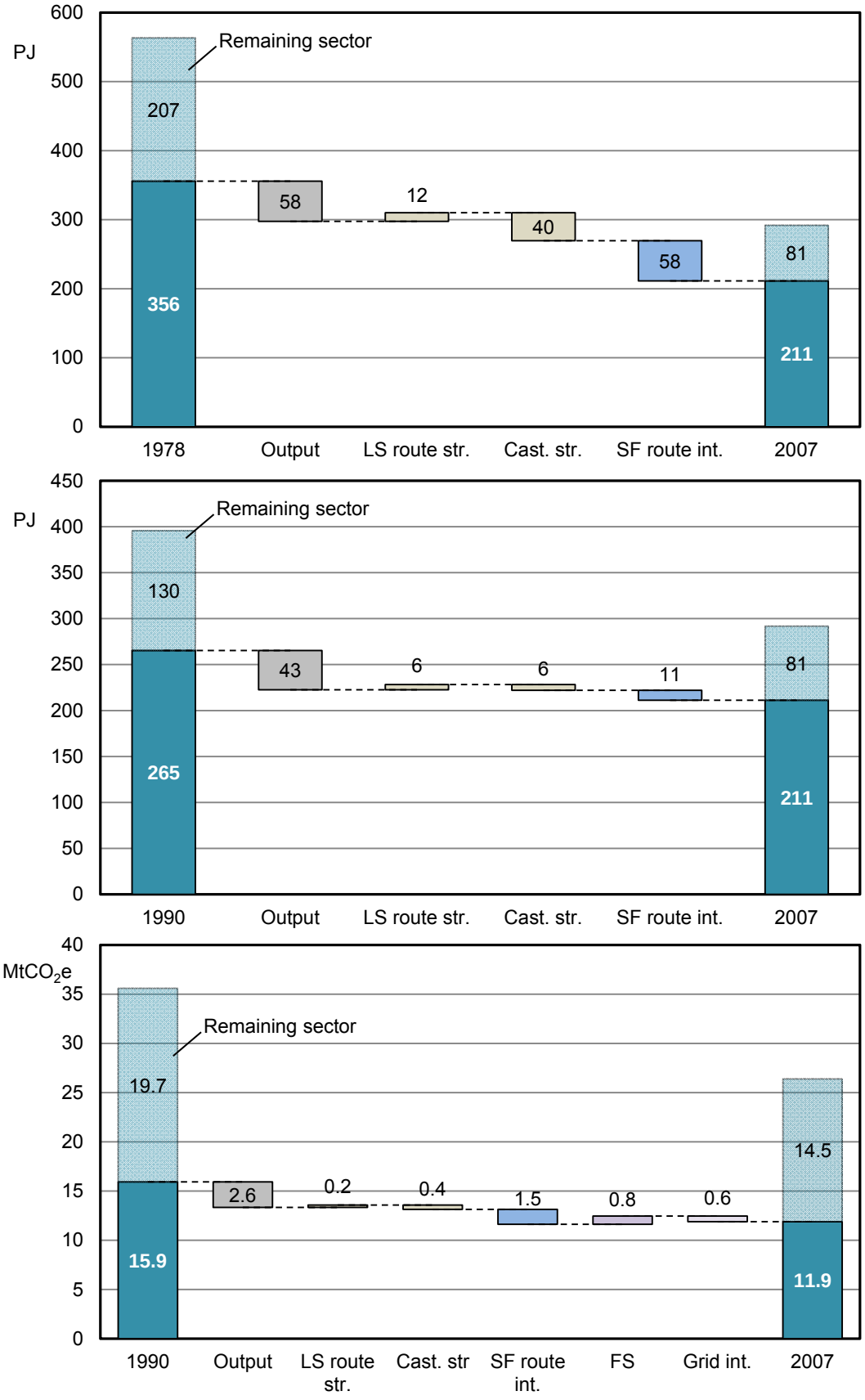

Figure 4-20: Waterfall charts of decomposed simple primary energy demand and GhG emissions from the UK semi-finished steelmaking system over the periods 1978-2007 and 1990-2007

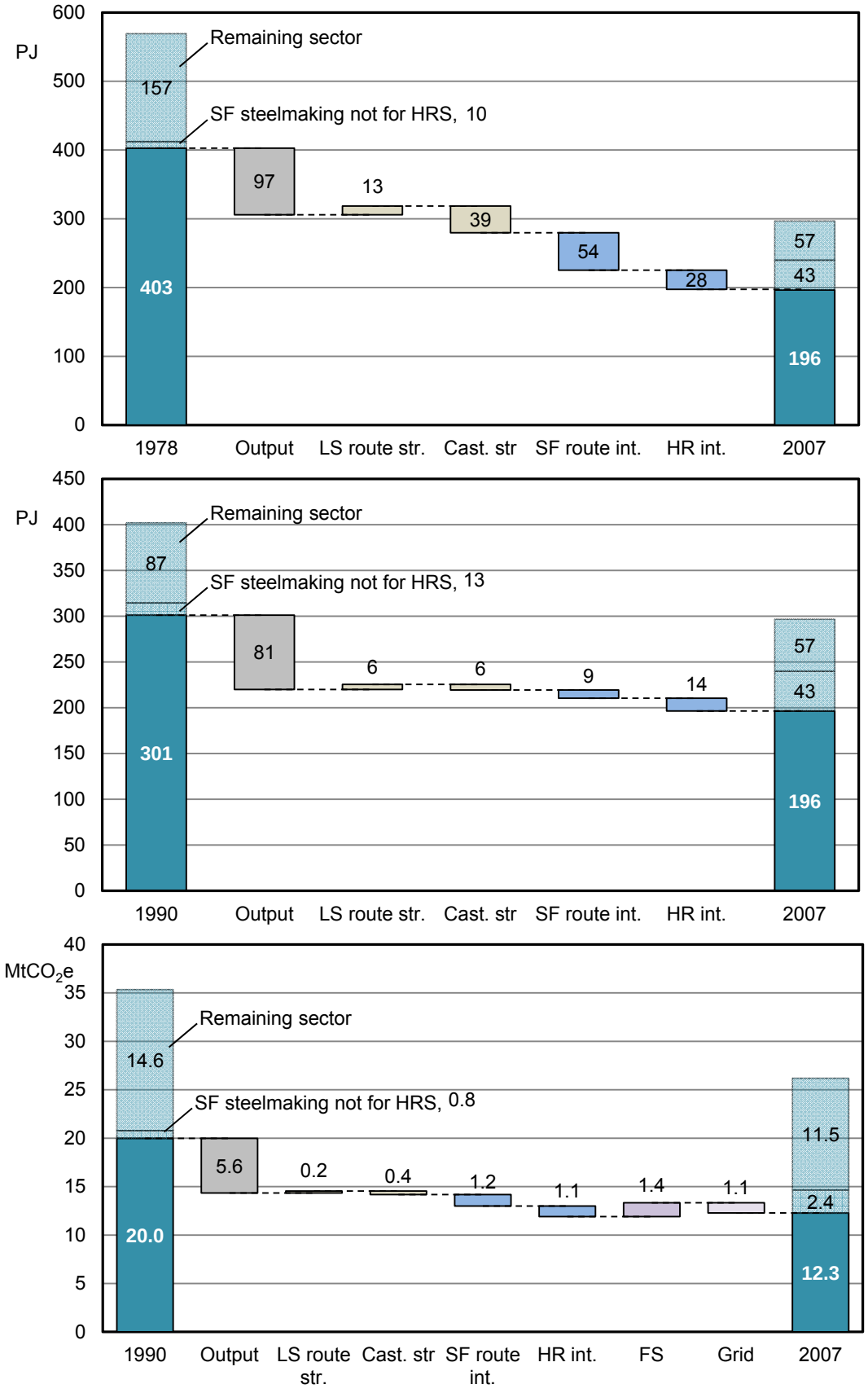

Figure 4-21: Waterfall charts of decomposed simple primary energy demand and GhG emissions from the UK hot-rolled steelmaking system over the periods 1978-2007 and 1990-2007

In summary, simple primary energy demand reduced by 26%, from 399PJ to 294PJ, over the 1990-2007 period and by 48%, to 207PJ, over the period 1990-2010. Total GhG emissions reduction over the same periods was 26%, from 36MtCO_2e to 26MtCO_2e, and 49%, to 18MtCO_2e, respectively. The marked difference in change between the two periods is attributed to the recent drop in production in the latter period. Simple primary energy and GhG emissions intensity over the period 1990-2007 reduced at a rate of 0.7% and 0.8% per year respectively. By contrast, each measure reduced at a rate of 1.8% per year over the period 1973-1990.

4.2.7 Baseline summary

Table 4-3 displays key figures defining the sector baseline in terms of absolute and specific energy and GhG emissions. Simple primary energy demand includes the direct energy losses and emissions from delivered electricity. NER and NRE (net requirement emission) include transport activities and level 2 (L2) processes. Process energy analyses using IFIAS conventions were conducted for these measures and are detailed in section A5.4 of the Appendix. As has been identified, the sector has made some significant technological investments since 2007. Principle among these was a BOF gas and heat recovery scheme at Port Talbot and a pulverised coal injection unit for the No.1 blast furnace at Teesside. These have been incorporated into an updated 2007 baseline (2007u). Comparison is also made here with 2010. Atypically low production at integrated steelworks is evident from a lower energy demand and higher average energy intensity.

System (% of sector crude steel production)	Energy demand	Primay energy demand	NER	Scope 1 GhG emissions	Scope 1-2/3 GhG emissions	NRE	SEC	SEC_p	NER	SE	SE_2	NRE
Unit:	PJ	PJ	PJ	$MtCO_2e$	$MtCO_2e$	$MtCO_2e$	GJ/tcs	GJ/tcs	GJ/tcs	$kgCO_2e$/tcs	$kgCO_2e$/tcs	$kgCO_2e$/tcs
2007:												
Sector (100%)	266	294	358	23.9	26.4	31.4	18.5	20.4	24.9	1660	1834	2184
Integrated steelworks (79%)	250	265	322	23.3	24.7	29.1	22.0	23.3	28.4	2053	2173	2563
EAF steelworks (21%)	16	29	36	0.6	1.7	2.3	5.3	9.4	11.9	186	562	764
2007u:												
Sector (100%)	262	290	355	23.7	26.2	31.3	18.2	20.1	24.7	1650	1824	2174
Integrated steelworks (79%)	246	261	319	23.2	24.5	29.0	21.7	23.0	28.1	2040	2160	2551
EAF steelworks (21%)	16	29	36	0.6	1.7	2.3	5.3	9.4	11.9	184	561	762
2010:												
Sector (100%)	186	207	250	16.3	18.2	21.5	19.2	21.3	25.71	1680	1873	2211
Integrated steelworks (75%)	174	184	222	15.9	16.8	19.7	23.7	25.1	30.2	2171	2300	2689
EAF steelworks (25%)	13	23	28	0.4	1.3	1.7	5.3	9.5	11.7	169	549	727

Table 4-3: Summary of baseline energy and GhG emissions for the UK iron and steel sector

4.3 Improvement potential

Thermodynamic and technical improvement potential is assessed in this section. Firstly, a detailed thermodynamic analysis is undertaken identifying the extent and location in the system of key losses in energy quantity and quality. Secondly, a comparison of the baseline with the best available technology (BAT) standard identified in literature is made.

4.3.1 Thermodynamic analysis

In order to examine the absolute limit to efficiency improvement potential and where it lies, it is necessary to apply thermodynamic analysis. For further detail and tabulated mass and energy balances, associated thermodynamic properties, and parameters, refer to sections A5.10 and A5.11.3 of the Appendix.

4.3.1.1 Method

Starting with process level mass balances and steelmaking structure, a full energy and exergy analysis can be applied to the UK steelmaking system. The chemical energy and exergy of mass flows is the enthalpy of devaluation and standard chemical exergy respectively. Thermal energy is calculated using mass flow temperatures, which were consulted on (Leach 2013) or assumed from literature (e.g., IISI 1998), along with material compositions (IEAGHG 2013a) and material properties (NIST 2013). The electrical energy carried in electricity flows are tabulated with the mass flow energies in section A5.11.3 of the Appendix. Remaining from the net of these energies, and some miscellaneous losses, such as those from mass leakages and phase changes informed from literature (De Beer et al. 1998a, Energy Audit Series 1982, IISI 1998, Michaelis 1998), is assumed the heat transfer to the surroundings. Heat transfer exergy is calculated from the energy counterpart using Equation (2-9), section 2.1.4, and estimations of average transfer temperatures informed by known process temperatures. Remaining in the process exergy balance after mass flow, electrical, and heat transfer exergies is assumed the exergy destroyed. This is the real exergy destruction, which can minimised up to the intrinsic exergy destruction, defined by Kotas (1985). Estimation of intrinsic destruction is based on specified assumptions about the fundamental attributes of processes as was previously attempted by Michaelis (1998).

It should be noted that cooling mediums, such as air or water, are not included inside the thermodynamic system boundary. Much of the thermal loss at the coke oven and sinter plant is therefore assigned to the hot product as opposed to the quenching water or cooler air flow respectively. Heat transfer loss encompasses the thermal energy that would be carried away by cooling water flows to regulate the temperature of plant structures. Transfer of heat to cooling water in particular is accompanied by a significant destruction of exergy (Szargut et al. 1988).

Process plant	Waste streams				Other			Total
	Chem. (h_{ch})	Thermal (h_{th})			Total	Misc.	q	
		Total	Product	Exhaust				
Coke oven	0.36	0.76	0.48	0.09	0.51	0.24	0.27	1.63
Sinter plant	0.11	0.99	0.56	0.36	0.32	0.00	0.32	1.42
Blast furnace	0.27	0.79	0.07	0.21	1.13	0.15	0.98	2.19
Basic oxygen furnace	0.50	0.43	0.09	0.13	0.78	0.00	0.78	1.71
Electric arc furnace	0.07	0.20	0.02	0.12	0.23	0.08	0.15	0.50
Continuous casting	0.00	0.72	0.68	0.02	0.79	0.26	0.53	1.51
Ingot casting	0.00	0.02	0.02	0.01	0.01	0.00	0.01	0.03
Hot rolling	0.00	0.80	0.40	0.36	0.60	0.00	0.60	1.40
All processes	**1.31**	**4.72**	**2.32**	**1.31**	**4.37**	**0.73**	**3.64**	**10.40**

Table 4-4: Breakdown of exergy losses from UK iron and steel process plant, GJ/tcs

4.3.1.2 Process and system losses

Presented in Table 4-4 and Table 4-5[22] is a breakdown of energy and exergy losses, respectively, for each of the key process plant in the UK iron and steel sector. The losses from each process are weighted to the sector level (GJ/tcs), for losses specific to process output refer to Table A-190 and Table A-191 in section A5.11.3 of the Appendix.

Chemical energy waste from the coke oven is mostly the unrecovered ammonia by-product. The large amount of thermal energy lost from the coke oven is carried by the 1100˚C coke, 900˚C raw coke oven gas, and the 225˚C exhaust flue gas. All of these may be targeted for heat recovery though, owing to its relatively low temperature, the exhaust flue gas has particularly low exergy.

Though specific thermal energy loss at the sinter plant is far lower than at the coke oven, it is a higher overall source of loss because the scale of sinter production in the sector is about three times that of coke. Most thermal energy waste at the sinter plant derives from the 600˚C sinter before entering the cooler section and 350˚C main exhaust from the sinter strand.

[22] The miscellaneous category is absent from Table 4-5 because most of these losses are classified as exergy destruction. The one exception is the exergy of mechanical losses at the coke oven, which was assumed 0.57GJ/tdc, or 0.16GJ/tcs (derived from, De Beer et al. 1998b), and is included in the total of 'other'.

Process plant	Waste streams				Other			Total
	Chem. (b_{ch})	Thermal (b_{th})			Total	q^b	b_d	
		All	Product	Exhaust				
Coke oven	0.44	0.35	0.22	0.02	1.30	0.18	0.96	2.08
Sinter plant	0.20	0.41	0.25	0.11	1.01	0.23	0.78	1.62
Blast furnace	0.42	0.33	0.05	0.05	3.13	0.73	2.39	3.88
Basic oxygen furnace	0.45	0.29	0.08	0.08	1.02	0.60	0.42	1.76
Electric arc furnace	0.05	0.13	0.02	0.08	0.39	0.12	0.28	0.57
Continuous casting	0.00	0.41	0.39	0.01	0.65	0.40	0.25	1.06
Ingot casting	0.00	0.01	0.01	0.00	0.02	0.01	0.01	0.03
Hot rolling	0.04	0.36	0.17	0.18	1.04	0.42	0.63	1.45
All processes	1.60	2.29	1.18	0.53	8.55	2.68	5.71	12.44

Table 4-5: Breakdown of exergy losses from UK iron and steel process plant, GJ/tcs

The main source of waste thermal energy from the blast furnace system is in the slag. Blast furnace slag tapped from the furnace has a temperature of over 1400˚C and thermal energy of about 0.4GJ/thm. Smaller amounts of thermal energy leave the system in the blast furnace top gas and stove exhaust flue gas. The stove flue gas has a temperature of about 250˚C and an associated 0.26GJ/thm which may be targeted for recovery. Some chemical energy is wasted in leaked blast furnace gas but it is assumed that all blast furnace dust and sludge is recycled and all slag is sold. Exergy destruction in the blast furnace is high owing to the extent and complexity of chemical transformations.

Chemical and thermal energy wastes relating to BOFG are 0.45GJ/tls and 0.17GJ/tls respectively, though have since reduced to an estimated 0.26GJ/tls and 0.1GJ/tls (in 2007u). Thus, approximately 0.36GJ/tls (0.29GJ/tcs) may presently be targeted from this area. About a third of BOF slag is recycled as iron bearing material in the sinter plant and the rest is assumed to be disposed of. In the EAF process up to 0.54GJ/tls of exhaust gas thermal energy may be targeted for recovery via scrap preheating. A key loss in the casting and hot-rolling processes is in the thermal energy of their products when cooled without recovery[23].

Overall, energy and exergy losses are well spread across the different processes although the largest sources of loss are concentrated at the heavy end of the integrated steelworks. In particular

[23] Hot charging in the sector is excluded from the table because it was not possible to obtain information for this measure as it is practiced in the UK. Nonetheless, the difference is likely to be overshadowed by the possible margin for error in the estimation of reheat furnace fuel requirement.

the blast furnace shows the greatest loss, though exergy analysis has shown it to be the principle location for exergy destruction. Around a third of energy and exergy losses arise from heat transfers to the environment (including via plant cooling media). Thermal energy loss from products, by-products and exhaust gasses amount to nearly half of all energy loss. However these outputs range in temperature and thermal exergy loss represents a quarter of all exergy loss.

Figure 4-22 and Figure 4-23 are Sankey diagrams of the 2007 UK semi-finished steelmaking system in terms of energy and exergy respectively. The 'band diagram' format introduced by Szargut et al. (1988) is applied. The system is split into constituent routes in Table 4-6 and Table 4-7, in which the total energy and exergy losses are summarised respectively. Energy loss from the BF-BOF route is more than double that of the BF-EAF route and triple in exergy terms.

System	Waste streams				Other			Total
	Chem. (h_{ch})	Thermal (h_{th})			Total	Misc.	q	
		Total	Product	Exhaust				
Steelmaking	1.28	3.76	1.84	0.89	3.69	0.72	2.96	8.72
BF-BOF route	1.52	4.27	2.09	0.96	4.14	0.74	3.40	9.93
BF-EAF route	0.35	1.81	0.87	0.64	1.97	0.67	1.30	4.13

Table 4-6: Breakdown of energy losses from the UK semi-finished steelmaking system split by route, units in units in GJ/tsfs from system and route

System	Waste streams				Other			Total
	Chem. (b_{ch})	Thermal (b_{th})			Total	q^b	b_d	
		Total	Product	Exhaust				
Steelmaking	1.51	1.86	0.98	0.34	7.29	2.21	4.92	10.66
BF-BOF route	1.84	2.06	1.10	0.32	8.50	2.53	5.78	12.40
BF-EAF route	0.27	1.09	0.52	0.39	2.69	0.99	1.69	4.05

Table 4-7: Breakdown of exergy losses from the UK semi-finished steelmaking system split by route, units in GJ/tsfs from system and route

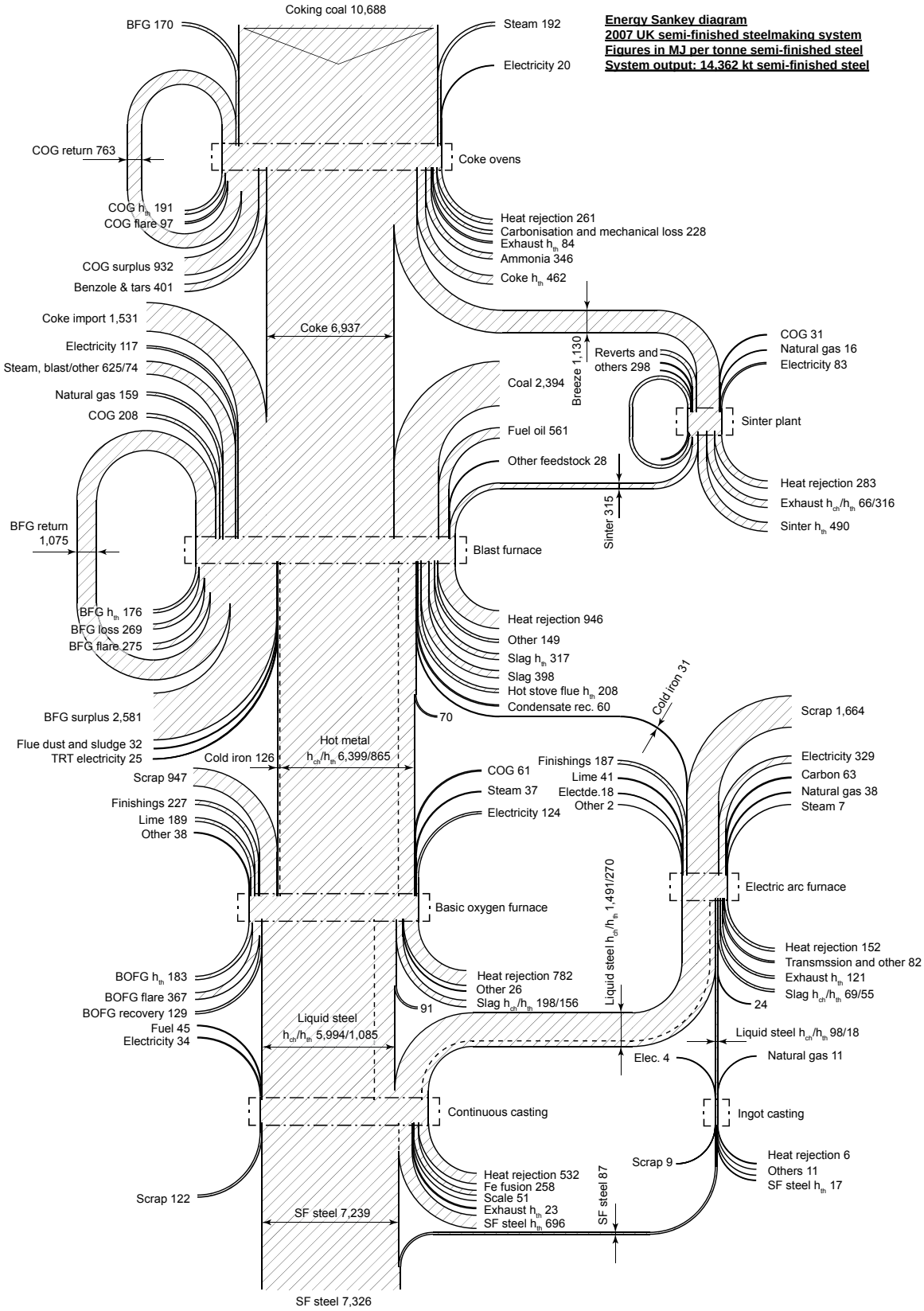

Figure 4-22: Detailed Sankey diagram of energy flows in the UK semi-finished steelmaking system

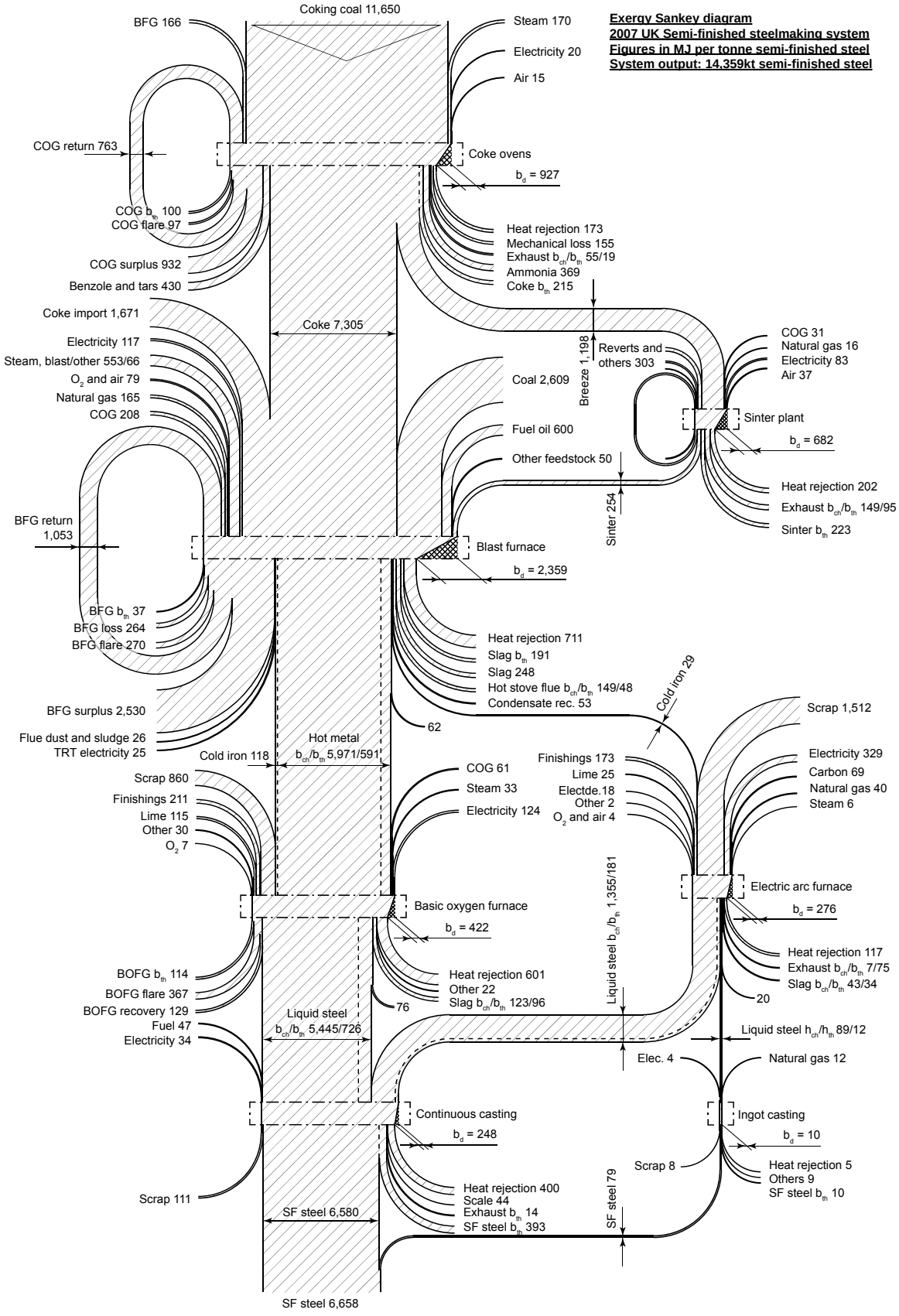

Figure 4-23: Detailed Sankey diagram exergy flows in the UK semi-finished steelmaking system

4.3.1.3 Intrinsic and avoidable exergy loss

Intrinsic exergy destruction at the coke oven is related to carbonisation and was calculated as 1.3GJ/tdc (0.37GJ/tcs) from the difference in exergy content of coking coal input and outputs coke, breeze, coke oven gas, tar, benzole, ammonia and wasted mass.

Intrinsic exergy destruction at the sinter plant is related to limestone calcination and agglomeration temperature. The standard chemical exergy associated with the calcination ($CaCO_3 \rightarrow CaO+CO_2$) of 133kg of $CaCO_3$ (based on 140kg of feedstock charged per tonne sinter) is 0.34GJ/ts. The degradation of energy associated with sinter at 1000˚C is the difference in thermal energy and exergy, which is 0.4GJ/ts. Total intrinsic exergy destruction is therefore 0.74GJ/ts (0.71GJ/tcs).

A rough calculation of intrinsic exergy destruction in a UK blast furnace was made by Michaelis (1998) and calculated to be in the region of 1GJ/thm. Adding to this a destruction at the hot stoves of 0.48GJ/thm (derived from, De Beer et al. 1998a) gives a total estimated intrinsic exergy destruction of 1.4GJ/thm (1.1GJ/tcs).

Intrinsic exergy destruction at the BOF may be calculated as the difference in thermal energy and exergy at 1600˚C of scrap and other cool furnace charge, which is about 0.1GJ/tls (0.08GJ/tcs). Irreversibility relating to oxidation and the pressure of injected oxygen inside the vessel would also have an impact but is difficult to measure. True intrinsic exergy destruction would therefore be some degree closer to the real destruction of 0.5GJ/tls (0.42GJ/tcs). Applying the same method for the EAF as the BOF, intrinsic exergy destruction at the EAF is about 0.5GJ/tls (0.11GJ/tcs).

The intrinsic exergy destroyed in casting and hot rolling is estimated by the change in thermal exergy of steel associated with its temperature reduction during each process. Steel is assumed to enter the casting machine at 1530˚C and exit at about 1000˚C (0.24GJ/tsfs) while steel cools during hot-rolling from 1200˚C to 800˚C (0.25GJ/thrs). These losses amount to 0.24GJ/tcs and 0.18GJ/tcs respectively.

Figure 4-24 summarises avoidable exergy losses which, in the absence of detailed knowledge on operational and other constraints, are conservatively presented as the mean of real and intrinsic exergy destruction subtracted from the total. The error bars represent the range resulting from each measure, intrinsic and real, of exergy destruction so may be considered the range for maximum of exergetic improvement potential. Total avoidable exergy loss summates to 6.7-9.7GJ/tcs (mean 8.2GJ/tcs): about two thirds of total exergy loss.

The difference between real and intrinsic destruction is most notable in the blast furnace. A significant amount of exergy is destroyed from irreversible phenomena occurring inside the furnace due to high temperature gradients and non-equilibrium reactions (Michaelis 1998). The

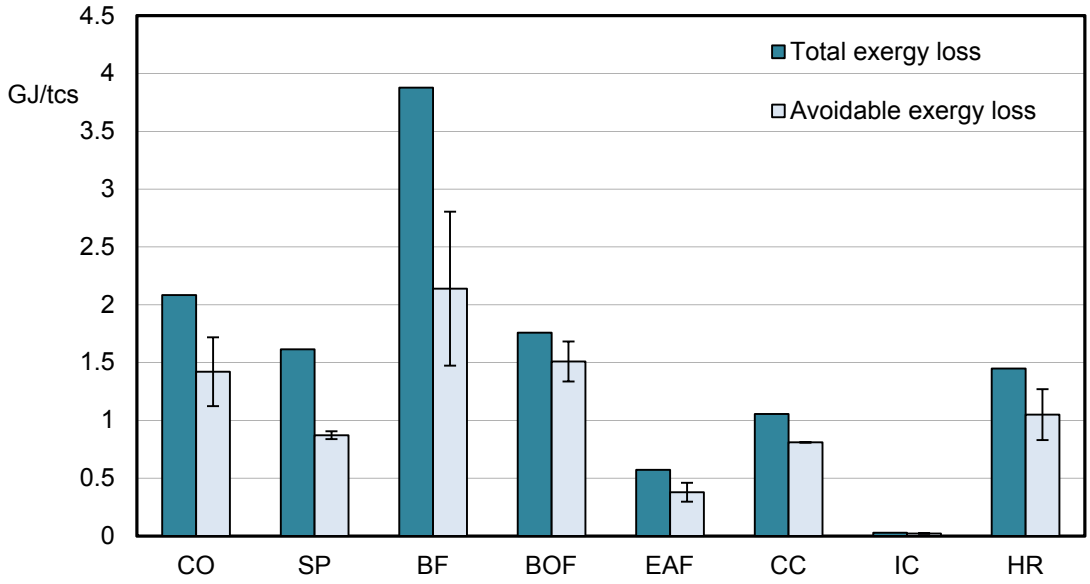

Figure 4-24: Total and avoidable exergy losses from processes of the UK iron and steel sector, specific to sector output

range indicates that up to 1.3GJ/tcs (1.7GJ/thm) of related exergy destruction may be avoided. This loss might be targeted by reducing feedstock particle size and increasing reactant residence time (ibid.). How much of this is presently targetable, however, is not certain and would depend on various external economic and operational factors.

4.3.1.4 Efficiency

Whereas the loss in a process is the difference between useful output and total input, efficiency is the useful output per total input. Table 4-8 displays process/system energy and exergy efficiencies. 'Process' refers to the efficiency with transit energy/exergy excluded and 'overall' refers to the efficiency that includes all inputs and all product outputs. Transit energies and exergies were identified as the chemical energies and exergies of coke (including breeze) output of the coke oven and steel outputs of processes downstream of ironmaking. The blast furnace has no transit energy or exergy because it is the only process that completely transforms base earth feedstock into man-made product. Transit energy is also absent in the sinter plant as the base earth feedstock is essentially the transit flow, and thus passes through negligible enthalpy of devaluation or chemical exergy.

Discounting transitory flows, it can be seen the blast furnace is the most thermodynamically efficient process in the sector. Within the furnace a large amount of feedstock energy is converted and locked into the product. Moreover, most of the thermal energy required for melting and chemical energy in by-product gas is passed on and dissipated at other processes.

Process/system	Process		Overall	
	η	ψ	η	ψ
Coke oven	58%	52%	87%	84%
Sinter plant	28%	20%	28%	20%
Blast furnace	85%	74%	85%	74%
BOF	43%	34%	81%	78%
EAF	36%	25%	79%	74%
CC	3%	4%	83%	86%
IC	2%	2%	74%	75%
Hot rolling	12%	8%	81%	79%
All processes	62%	55%	82%	78%
HR steelmaking	60%	54%	82%	78%
BF-BOF route	63%	56%	82%	78%
BF-EAF route	25%	19%	81%	79%

Table 4-8: Process and overall energy and exergy efficiencies of systems and processes of the UK iron and steel sector

Efficiency at the sinter plant is low because for much of the process chemical energy input is necessarily transformed in combustion and there is no heat recovery. In contrast, the steel furnaces recover most heat by the transfer thermal energy in the liquid steel product. Product heat from casting is lost but may be curbed by hot-charging the rolling mills. This loss would be substantially reduced by integrating casting and rolling in what is known as 'near net shape casting'. Hot-rolling process efficiency is slightly higher than casting as some of the thermal energy of combustion is recuperated by the reheat furnace. The coke oven has relatively good efficiency owing to the recovery of chemical energy in most of the by-products of coal carbonisation, although thermal energy in the product and by-products is unrecovered.

The significant chemical conversion to new iron at the heavy-end of the integrated steelworks is why the primary route has significantly higher process efficiency than the secondary route, despite a similar overall efficiency. Essentially the secondary route begins with a thermodynamically valuable feedstock of low economic value, and increases only its economic value. The primary route begins with feedstock of low thermodynamic value and raises both economic and thermodynamic value.

4.3.2 Technical potential

Technical potential is measured here by comparing the baseline to best practice technology (BPT) and best available technology (BAT). BPT and BAT are classified here based on the definitions of the International Iron and Steel Institute's (IISI) EcoTech and AllTech plant respectively (IISI 1998). BPT is therefore defined as the best performing proven technology that is economically attractive and BAT is defined as the best performing proven technology regardless of financial viability. The purpose of including both BAT and BPT classifications is to suggest a range for economically viable improvement potential. However, it should be noted that the economic viability of a technology is also a site-specific variable.

In cases where BAT is perceived to be economically attractive, it is both BAT and BPT. Either way, cost reductions can generally be expected over time. BAT can also be established anew with improved technology demonstration and deployment. With the exception of the EAF, this assessment identifies all BPT plant as EcoTech and all BAT as AllTech. The BAT for EAF is the Simetal EAF Quantum™ (Siemens VAI 2011a) and the AllTech EAF has been demoted to BPT. In an overview assessment by Worrell et al. (2008) the best standard includes thin slab casting, which integrates the processes of casting and hot-rolling. However the concept may only be suitable for a proportion of steel industry product (US EPA 2012). Nevertheless the assessment here focuses on improving existing processes in the UK so thin slab casting is excluded.

The average performance of UK process plant at three different years, reflecting data availability, is compared with BPT and BAT in Figure 4-25. The base year (2007) has been updated (2007u) to include key investments made hitherto. Specifically, this includes a BOFG gas and heat recovery scheme and increased blast furnace coal injection. Performance is compared on the basis of end-use energy efficiency (A), primary energy efficiency (B) and specific GhG emissions (C). End-use energy efficiency, or SEC, is defined as the net demand of direct energy per unit of plant product, where the product is indicated in brackets. Energy demand includes the NCV of fuel, the thermal energy of steam or condensate, and electrical energy. Primary energy efficiency includes direct energy demanded in the production of electricity, steam, and oxygen inputs. A comparison is also made in Figure 4-26 for hot-rolled steelmaking system primary energy efficiency.

A number of adjustments have been made to the source data to ensure a level playing field. Due to the large energy throughput in the coke oven, and thus potential for error, coke yield energy loss (net energy of feedstock and products) is fixed for all at the 2007 UK average of 1.57GJ/tdc. Because of variability in operating conditions the carbon input to the EAF is fixed at 19kg/tls (Entec UK Ltd. 2006a). Hot rolling BAT and BPT is the average of hot-strip mill, plate mill and section mills reported in IISI (1998) but weighted to UK plant outputs in 2007.

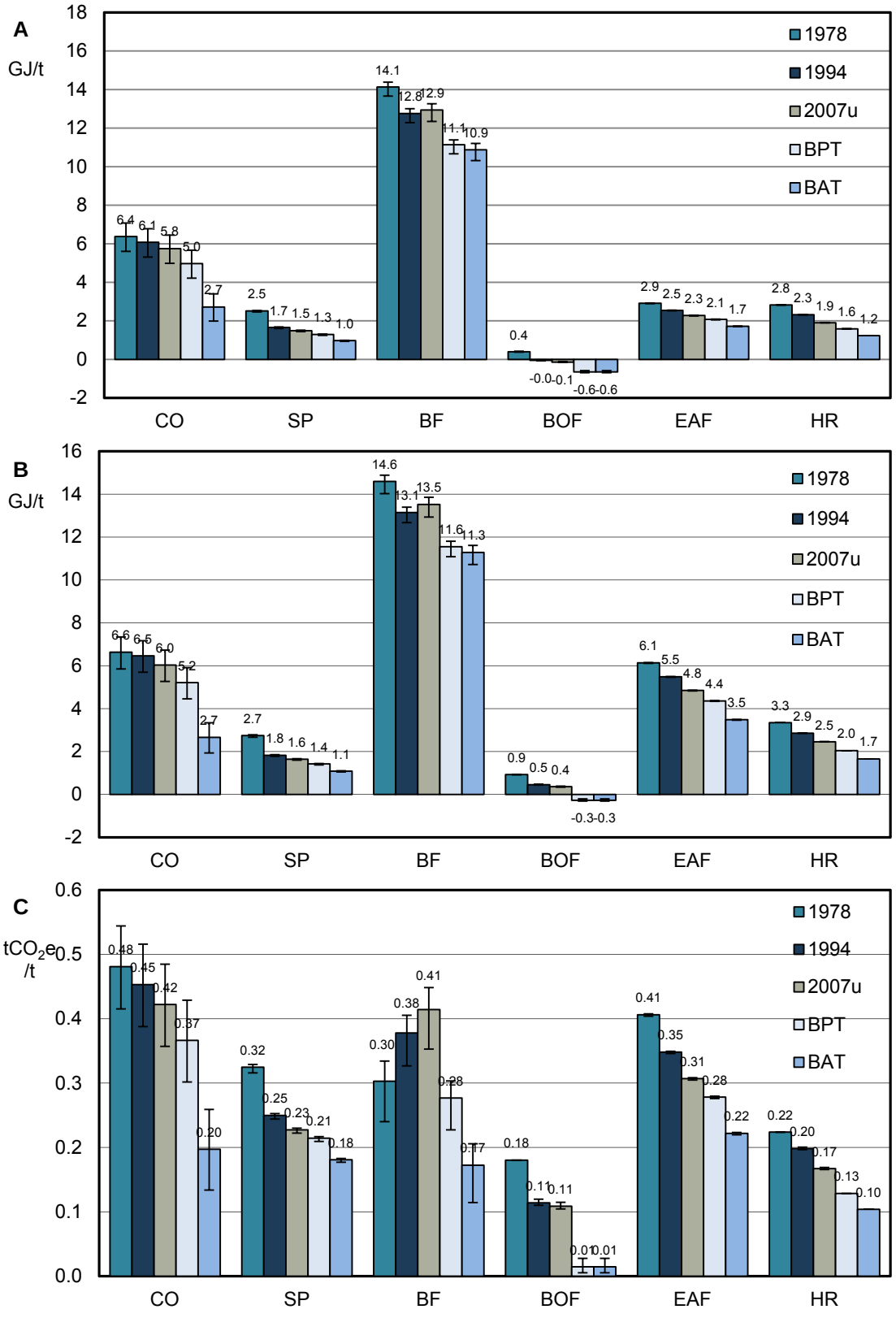

Figure 4-25: Comparison between average UK iron and steel process plant efficiencies of 1978, 1994 and 2007 with best practice and best available technology in terms of end-use energy (A), primary energy (B) and greenhouse gas emission (C)

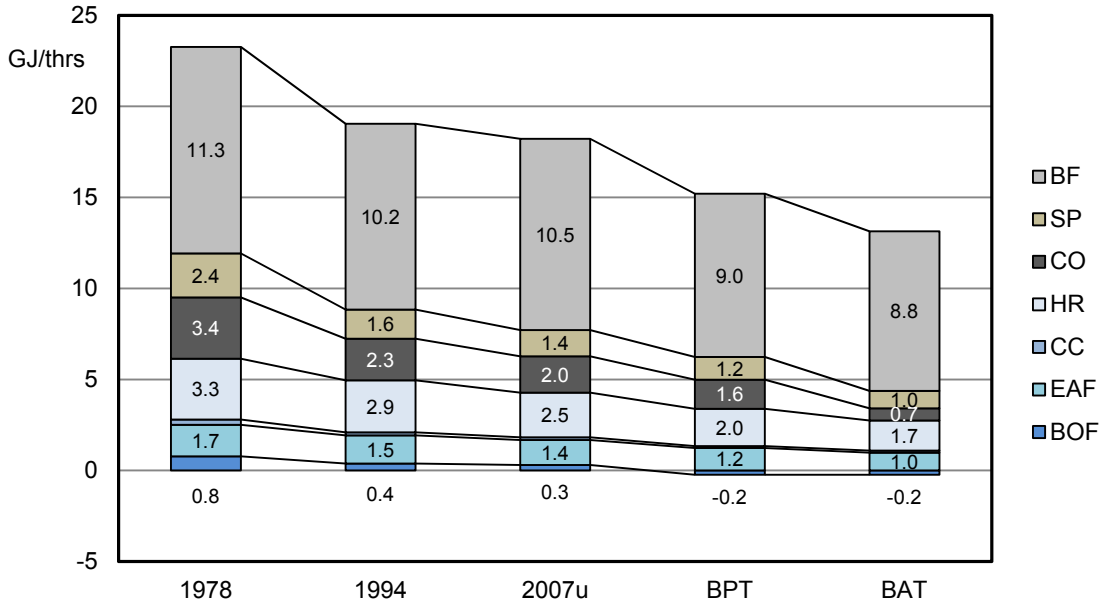

Figure 4-26: Comparison between average UK hot-rolled steelmaking (2007 structure) of 1978, 1994, and 2007u (updated for recent improvements) with world BPT and BAT standard

For the estimation of specific GhG emissions the proportion of natural gas, blast furnace gas and coke oven gas in 2007 for each plant is maintained except the blast furnace in which the ratio of BFG consumption and production is maintained. BOF metallic feedstock share is maintained at the 2007 level and coke consumption at the blast furnace is balanced with coke production. Conversion of steam and electricity to primary energy is achieved assuming average sector boiler efficiency and UK grid efficiency respectively.

The error bars in Figure 4-25 take into account potential error in fuel NCV, which was informed from technical literature (European Commission 2012b, IEAGHG 2013a, IISI 1998) and correspondence with the sector (Lewis, B., TATA Steel, pers. corr., April 2014). The dry basis NCV for coking and injection coal is 31GJ/tonne (range 29.5-32 GJ/tonne) and for coke is 29.5GJ/tonne (28.5-30GJ/tonne). The NCV of COG ranges by the same degree as coke. BFG NCV is influenced by coal injection rate but for simplicity is fixed. BOFG has been allocated an NCV of 8GJ/Nm^3 (range 7-8.7 GJ/Nm^3).

It can be observed from Figure 4-25 that the blast furnace is the most energy intensive process. The coke oven is another intensive energy user and is comparable to the EAF in primary terms. Negative energy values for the basic oxygen furnace are possible due to the large input of thermal and chemical energy from hot metal, which is not counted here. Specific GhG emission from the blast furnace is less than its fuel input would imply. This is partly due to the absorption of some carbon in the iron product but mainly due to non-equilibrium conditions in the furnace producing excess CO. This is measured by the production of BFG which has a high emissions factor specific to CV. Improvement rate in Figure 4-26 is shown to slow significantly from 1994, despite the degree of technical improvement potential from both BPT and BAT.

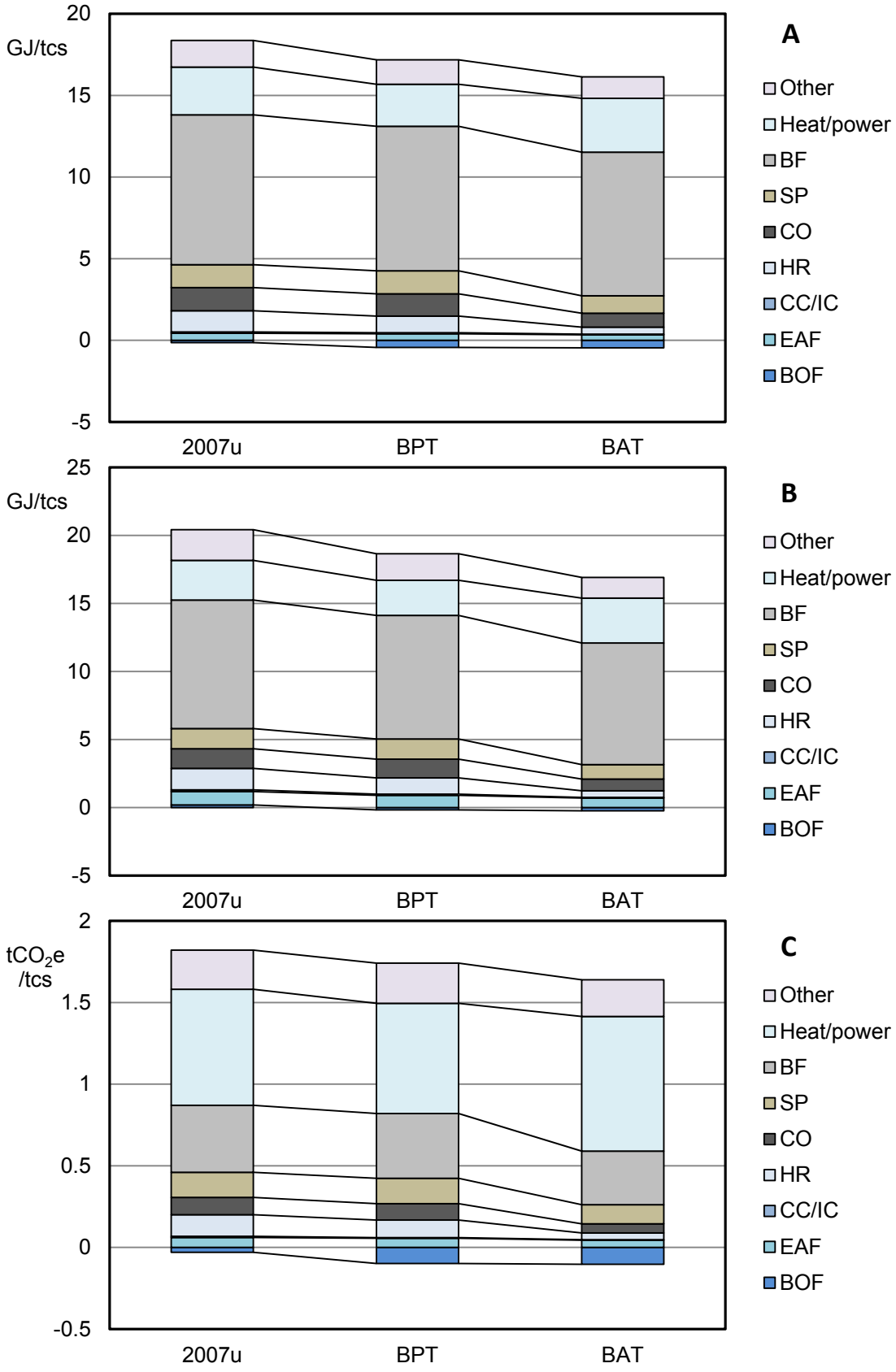

Figure 4-27: Comparison of average UK iron and steel sector performance in 2007 (updated with recent improvements) with world BPT and BAT incorporated at the site level

System	SEC	SEC_p	SE_2
Iron and steel sector	8-14%	10-18%	8-14%
Integrated site	8-13%	9-17%	8-13%
EAF site	11-31%	10-30%	11-29%

Table 4-9: Energy and GhG emissions improvement potential in the UK Iron and steel sector from existing process improvement

Figure 4-27 compares the baseline to BPT and BAT at the sector level. For this comparison the BAT and BPT process plant were modelled into the baseline manufacturing sites. As generated steam and electricity is now within the system boundary, these particular flows have no primary energy or emission factor. The demand for electricity generated onsite is typically prioritised for key plant in case of utility failure (IISI 1998). For the sake of meaningful comparison, the split between purchased and non-purchased electricity demand at the integrated site is applied at the process level. The improvement potentials are summarised Table 4-9.

Considering the wider system provides a more accurate representation of process improvement as it includes the unavoidable combustion of all by-product gasses. For example, much of the carbon flowing through the blast furnace is emitted via the combustion of BFG at boilers. Lower process fuel demands and greater recovery of process heat at the BAT integrated site leaves more BFG available for the production of onsite electricity. The emissions relating to this generation is far greater than the emissions relating to the generation of purchased electricity.

4.3.3 Summary

Figure 4-28 compares technical improvement potential at the process and site level with the total of identified process energy losses. Energy loss is to 10.1GJ/tcs and is split into components of chemical and thermal energy waste, heat transfer, and miscellaneous. BAT potential is relative to the 2007u baseline and the energy losses have been adjusted from the results in section 4.3.1 for 2007u.

The theoretical minimum energy requirement for producing steel is assumed approximately equal to the enthalpy of devaluation of steel, which is 7.5GJ/t (see section A5.3 of the Appendix for derivation). It therefore follows that the complete net direct SEC, i.e. all material and energy inputs less useful by-product outputs, of the steelmaking processes up to hot-rolling is 17.6GJ/tcs. Thus the theoretical limit of improvement is 57%. At the level of BAT this improvement is limited to 42%. Thus, reaching BAT with existing processes achieves 26% of the theoretical potential for improvement.

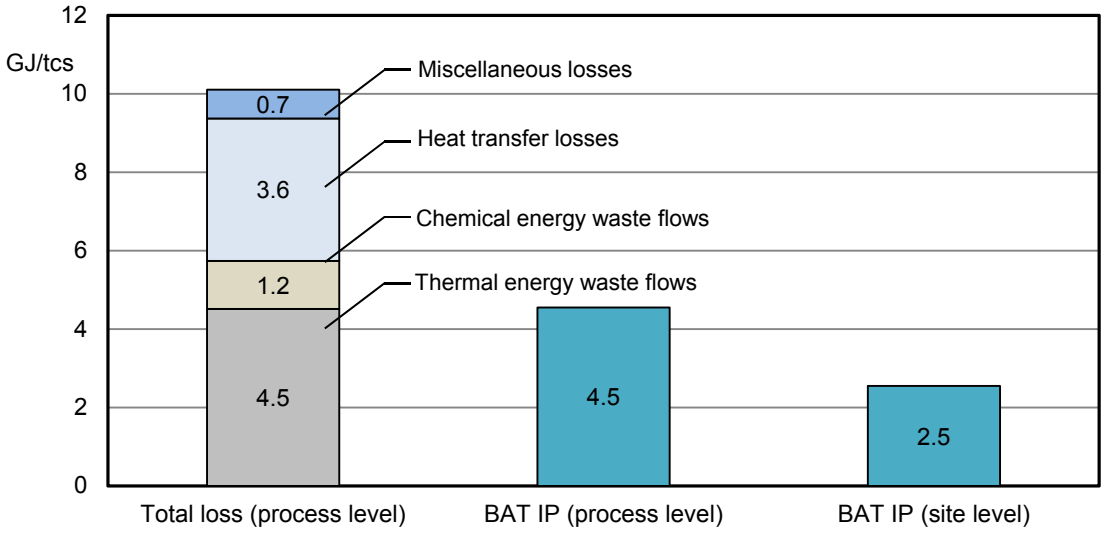

Figure 4-28: Comparison of thermodynamic process improvement potential with technical improvement potential of SEC at the process and site level for the UK iron and steel sector

The reduction in SEC of 4.5GJ/tcs offered by the BAT process measures equates to a significantly lower saving, 2.5GJ/tcs, at the site level: an improvement on sector SEC of 14%. The effect is amplified for GhG emissions of which the site reduction potential is 255kgCO_2e/tcs (scope 1-2/3), or 14%, down from 487kgCO_2e/tcs at the process level. The site saving is minor compared with the sector's expected contribution to the UK's legislated national target of an 80% reduction from 1990 levels by 2050.

4.4 Technological identification and representation

Leading on from the analysis on improvement potential, key technologies and measures associated with improvement are identified and modelled into the baseline. Technologies were chosen on the basis that they may feature in the UK iron and steel sector in the time to 2050.

Because of the integrated nature of iron and steel production it is not possible to model the uptake of a technology in isolation. For example, any change to the demand by a process of internally produced fuels, steam or electricity, affects the availability or production of those inputs elsewhere onsite. Thus the effect of any technology or measure is evaluated at the site level. Tabulated resource balances of the modelled technologies and their integration into the modelled UK sites can be found in section A5.11.2 of the Appendix. Choice of a number of configurations and equipment options has also been built in to the model and are described in section A5.6 of the Appendix.

The technologies themselves fall into different categories. Those that are 'additional' could technically be retrofitted to existing process plant. Those that are 'replacement' entail substitution by the technology of one or a collection of process plant. Some may be installed without affecting site configuration whereas some imply major process integration or radical structural transformation at the sector level.

4.4.1 Existing additional technologies

4.4.1.1 Coke oven

The main source of energy recovery from UK coke ovens is from the thermal energy of coke. As hot coke is discharged from the ovens it is quenched with water to avoid oxidisation. It may instead exchange heat with a stream of inert gas (IISI 1998). The heated gas is then passed to a waste heat boiler to raise steam. This well-established technology is known as coke-dry quenching.

The integrated steelworks may utilise this steam for direct process needs or for generating electricity. A number of effects may arise from this. Firstly, some of the natural gas currently fed to boilers may be reduced. Secondly, the consumption of BFG and COG at the boilers may also be reduced, leaving more available for substituting natural gas elsewhere. Thirdly, more steam is available for the production of onsite electricity, thereby displacing the combustion of a mix of fuels, including coal, at power stations. The effect is modelled here as a reduction in the integrated site's consumption of natural gas associated with 1.4GJ/tdc of steam (IISI 1998) generated by existing boilers.

The instalment of coke dry quenching technology is a significant undertaking that would have to coincide with the major refurbishment or replacement of aged coke oven batteries. The UK operates aging coke oven batteries which would suggest opportunities in the short-medium term.

4.4.1.2 Sinter plant

Heat in the exhaust gas leaving the sinter strand may be recovered by recirculating a proportion as combustion air (IISI 1998). The result is a reduction in the amount of coke breeze required in the sinter feed by about 0.13GJ/ts.

Hot sinter entering the cooler transfers its thermal energy to the cooler air which can in turn be targeted for heat recovery. Heat may be recovered in a number of ways including preheating raw materials, preheating combustion air, and steam generation. By utilising the energy in a waste heat boiler about 0.17GJ/ts of steam may be generated (IISI 1998). This could lead to a reduction in natural gas consumption at existing boilers.

4.4.1.3 Blast furnace

About 0.1GJ/thm at the hot stoves has been indicated as technically recoverable by preheating combustion air with heat from the exhaust flue (IISI 1998). Hot stove efficiency is also influenced by a number of other factors including cycle times, operating practice, hot blast temperature,

excess combustion air, combustion air O_2 enrichment[24] and fuel CV (IISI 1998). UK blast stoves in 2007 operated with a hot stove fuel demand of 1.93GJ/thm, compared with 1.44GJ/thm at the BAT stoves (DECC 2013a, IISI 1998). Thus a 25% reduction in stove fuel demand is assumed possible.

Some energy in the top-gas may be technically recoverable via the application of new TRT technology. However the saving would be small and is perhaps only viable at one of the remaining blast furnaces without the technology. It has therefore been excluded as a potential measure.

Despite significant progress already made, the limits stated in literature (Ghosh and Chatterjee 2008) suggest that their remains potential to increase fuel injection rate. The limit of coal injection in blast furnaces could be as high as 250kg/thm, or half of fuel rate mass. In 2007 the sector injected an average 113kg/thm of coal and 18kg/thm of fuel oil, amounting to a coal injection equivalent of about 120kg/thm. In 2012 remaining fuel oil injection was replaced with PCI injection of up to 235kg/thm. Since then the sector has achieved an average of up to 150kg/thm. It is assumed that this average could increase to 200kg/thm. The estimated increase is conservative compared with the limits suggested and used in the absence of detailed, plant-specific technical information. Nonetheless the baseline has been modelled with an adjustable injection limit.

Alternative fuel injectants such as charcoal or waste plastics have been proven (European Commission 2012b). Provided the wood is sourced sustainably and the plastics would otherwise be incinerated without recovery, these may be considered carbon neutral resources. However their use would lower the overall limit to coke substitution in the sector and so maximising coal injection has taken preference here.

Total fuel injection rate was measured to be 15.3GJ/thm in 2007 and has remained fairly consistent since, though lower fuel rates in the past are apparent (DECC 2013a). It is noted that there is significant margin for error in assessing fuel rate without detailed, plant specific fuel CV data for inputs at frequent time intervals. However, opportunities exist for reducing fuel rate, such as increasing reaction residence time for optimum combustion (Michaelis et al. 1998). The rate of 15.1GJ/thm indicated by IISI (1998) for the BAT blast furnace is assumed to be achievable.

4.4.1.4 Basic oxygen furnace

As was previously identified in the baseline, there may be potential for capturing more of the chemical and sensible energy in basic oxygen furnace gas. As much as 0.74GJ/tls of BOFG and 0.17GJ/tls of generated steam has been reported (IISI 1998). This translates to an additional

[24] As is separate from blast O_2 enrichment and is unlikely to be economical unless there is excess O_2 available onsite.

recovery of 0.58GJ/tls of chemical energy, giving a total of 0.75GJ/tls of available energy recovery from the 2007 baseline (incorporating improvements in 2010 equates to an estimated potential of about 0.4GJ/tls of BOFG and 0.1GJ/t of steam). The increased recovery of BOFG and waste heat boiler steam leads to a decrease in natural gas consumption at the site level.

4.4.1.5 Electric arc furnace

The main opportunity for recovering energy at the electric arc furnace is by using the sensible energy in exhaust gasses to preheat the metal scrap feedstock. The assumed effect is a reduction in electricity demand of 0.25GJ/tls (IISI 1998). This equates to the same saving in exergy and a primary energy reduction of nearly 0.7GJ/tls.

4.4.2 Existing replacement technologies

4.4.2.1 Near net shape casting

The casting of thin slab or strip directly from liquid steel integrates the two-step process of casting liquid steel into the semi-finished form and reheating with hot rolling. The technology is limited in coverage in that it may only be applied for the production of certain steel shapes (US EPA 2012). A maximum substitution of 33% of hot-rolling output is suggested here. The energy requirement of this technology is about a tenth of the combined energy requirement of the substituted processes (IISI 1998).

4.4.2.2 Simetal EAF Quantum™

This optimised EAF design represents the state-of-the-art in secondary steelmaking (Siemens VAI 2011a). Electricity demand is reported as 280 kWh/tls (1GJ/tls), which is two thirds of the modelled UK EAF average. Electrode consumption is also reduced to 0.9kg/tls, which is less than half the UK baseline rate.

4.4.2.3 Electric arc furnace

The average UK electric arc furnace site produces steel at about 40% the primary energy demand and a quarter the GhG emission of the average integrated site. By increasing relative production from the electric arc furnace route, the average energy and emissions intensity of UK steelmaking can be significantly reduced. This route also synergises with ambitious aims in the UK to decarbonise the electricity supply (HM Government 2011).

Since its pre-1980 peak, crude steel production from the BF-EAF route halved as a proportion of total production to below 20%. The model incorporates any level of future structural change.

4.4.2.4 Increasing scrap input to BOF

The production of iron per unit of steel can be reduced without any purchase of capital equipment if a greater amount of scrap metal is charged to the BOF. Scrap concentration in the BOF metallic charge is about 15%, reduced from 25% in the 1970s. A concentration of up to 35% scrap is assumed technically feasible (Barker et al. 1998, Langley 1984b). The model incorporates scrap concentration within the range 15-35%.

4.4.2.5 Direct-reduced iron (DRI)

Direct reduction is the reduction of iron ore below its melting point. High quality ore is reduced by exposure to a reducing gas. The gas is a syngas reformed from either coal or natural gas, the latter being the most common and environmentally attractive of the two. The most common natural gas based DRI process in use is the MIDREX process (IEA 2007). This is a shaft furnace in which the reducing gas is fed through a number of ports around the furnace periphery. The iron ore burden is charged at the furnace top and oxidises with the reducing gas as it descends. The gas reformer generates the reducing gas from natural gas and is heated to around 1000˚C via the combustion of process waste gas blended with preheated natural gas and combustion air (IEAGHG 2013b, IISI 1998). Preheating is achieved through the recovery of combustion exhaust gas heat in a recuperator. Natural gas requirement is about 10.4GJ/tdri (IEA 2009c). The associated steelmaking route uses an electric arc furnace.

The economics of running a DRI unit has prevented it from competing with the blast furnace route except in parts of the world with a cheap supply of natural gas, iron ore availability and/or a demand for scrap substitutes (IISI 1998). The technology is particularly sensitive to natural gas price. Two 400kt/y MIDREX units were constructed in Hunterston, Scotland in 1980 (Smith 2011). However a predicted drop in the price of natural gas, relating to its exploitation in the North Sea, never materialised and the plants were mothballed for 15 years before being dismantled and shipped to the USA. After just two years of production the plant were again mothballed as a result of challenging fuel prices, after which they were shipped to Saudi Arabia. Due to an unforeseen significant reduction in fuel price, relating to shale gas fracking, the US is once again investing in DRI (ibid.). Shale gas extraction in the UK is a possibility, though the scale of it is uncertain.

DRI is typically converted in an EAF. A Greenfield UK MIDREX steelworks was constructed by combining the technology with an EAF, continuous caster and hot-rolling mill. The model incorporates an EAF scrap input of 30-70% metallic charge. Under normal conditions metallic charge is assumed to be 40% scrap to 60% DRI (IISI 1998).

4.4.3 Future additional technologies

4.4.3.1 Slag heat recovery

Slag heat recovery systems have been under development for at least 30 years but none have yet been applied commercially (IISI 1998, US EPA 2012). To do so would require the slag to be granulated and dry cooled in a reliable, efficient way that would not degrade slag quality. The hot cooling air could be used to raise steam equating to 0.35GJ/thm. The subsequent effect of this has been modelled as a reduction in the consumption of natural gas for the production of that amount of steam energy via the existing boiler system. The model provides the option to include this technology as future BAT.

4.4.3.2 Carbon dioxide separation equipment

The CO_2 emitted at key point sources at the integrated steelworks can be targeted for capture with separation technologies such as amine scrubbing. CO_2 in the flue gas of the hot stoves and the boiler plant at the integrated steelworks is modelled based on absorber technology with MEA (detailed in, IEAGHG 2013a). To all other sites with capture the option of applying MDEA or VPSA separation technology has been modelled. Capture efficiency can vary depending on the concentration of CO_2 in the input stream. Capture efficiency is assumed to between 85% and 90% and the model includes the option to change capture efficiency per site.

Captured CO_2 may be abated by storing it underground: carbon capture and storage (CCS). It may also be abated through its utilisation in certain applications: carbon capture and utilisation (CCU). Examples of CCU include substituting certain chemical feedstocks and fuels, accelerating mineral carbonation, and facilitating growth of microalgae as a source of biomass (Centre for Low Carbon Futures 2011). CCS and CCU may be collectively referred to as carbon capture, use and storage (CCUS).

4.4.4 Future replacement technologies

The processes assessed here were identified for future low carbon steelmaking in Europe under the ULCOS programme. The ULCOS (Ultra Low CO_2 Steelmaking) programme is a consortium of steel and allied companies operating in Europe with the objective of halving GhG emissions from the sector by 2050 (IEAGHG 2013b). Four key technologies were identified for this objective: TGR-BF, HIsarna, ULCORED, and electrolysis. The first three of these technologies are intended to rely on CCS while the last depends on a source of low-carbon electricity. The four options have been incorporated into the model. These and other emerging technologies for iron and steel production worldwide are reviewed in IEAGHG (2013b).

4.4.4.1 Top gas recycle blast furnace (TGR-BF)

In the TGR-BF the hot blast is replaced with nearly pure oxygen, resulting in a CO_2 rich top gas (IEAGHG 2013a). The CO_2 is separated from the top-gas and the resulting process gas is recycled back into the furnace to reduce coke rate. The high concentration of CO_2 in the top-gas enables the choice of a number of technology options including amine scrubbing, cryogenics, and physical absorption technologies such as pressure swing absorption (PSA) and vacuum pressure swing absorption (VPSA). The captured CO_2 may be compressed and delivered to a storage pipeline (CCS) or sold for CCU applications of variable abatements.

The technology has been modelled in literature as using either Methyl diethanolamine with Piperazine (MDEA/Pz) based separation equipment (IEAGHG 2013a) or VPSA (Danloy et al. 2008). The former analysis applies to the blast furnace a coke rate of 259kg/thm and coal rate of 152kg/thm, while the latter, described as version 4 (V4), has rates of 187kg/thm and 180kg/thm respectively. The model enables choice between separation technologies and fuel rates.

It has been simulated under the ULCOS project that this technology could reduce emissions at the blast furnace by a quarter (Danloy et al. 2008) though this would be lower at the site level due to a reduced surplus in by-product gas (IEAGHG 2013a). Combined with CCS, site emissions may be halved (ibid.).

The concept is long established and the technology has been in development under ULCOS since 2000. It was tested successfully in 2007/8 at small scale at LKAB's experimental blast furnace in Lulea, Sweden. It is now in the full-scale demonstration phase. The conversion of a blast furnace at Eisenhüttenstadt, Germany, with version 3[25] configuration is on-going and conversion of the ArcelorMittal blast furnace P6 in Florange, France, with version 4 is planned though progress has stalled since some of the funding was withdrawn (Zep 2013).

A UK based TGR-BF steelworks was constructed by replacing the blast furnace at the baseline integrated site with the blast furnace incorporating the technology. TGR-BF process gas that is surplus to recycling is directed at replacing the demand previously supplied elsewhere by blast furnace gas. Due to a lower amount of surplus energy than was the case with blast furnace gas, as well as a reduction in coke oven gas due to lower coke oven output, there is an energy supply deficit from by-product gasses. A greater demand for steam is also required if MDEA separation equipment is applied. Ultimately these changes lead to increased purchases of natural gas. It is assumed that the level of onsite electricity generation is to be maintained. Generation technology is unchanged though additional boiler capacity is incorporated where there is a need to increase

[25] Version 3 injects process gas into the main tuyères only. Version 4 also injects into the stack tuyères.

steam requirements. The additional demand for oxygen from the TGR-BF is met by an onsite low purity air separation unit (ASU).

4.4.4.2 HIsarna

The HIsarna process is a direct smelting reduction process that integrates the processes of the sinter plant, coke oven and blast furnace. The HIsarna system is based on a combination of three technologies: the cyclone converter furnace (CCF) for pre-reduction of ore, the Hismelt furnace for final smelting of the pre-reduced ore, and a thermally heated screw for coal pyrolysis producing a char which is fed to the smelter (IEAGHG 2013b). For a detailed description of the process the reader is referred to (Dry and Pilote 2013).

The CCF makes up the top portion, or mouth, of the smelting vessel. Iron ore fines are charged into the CCF where they are melted and pre-reduced (20% reduced). Oxygen is injected into the cyclone chamber to partially combust off-gasses providing heat for melting. The oxygen and ore fines are injected tangentially into the chamber so as to create a cyclonic swirl about a vertical axis. Entrainment of iron ore fines into the ascending reduction gasses is prevented by centrifugal forces which impel them to the sloping inner wall after which they drop down into the main smelter bath. The wall is water cooled to prevent the fines from sticking.

Oxygen is also delivered to the smelter, via lances, for post-combustion heat (IEAGHG 2013b). The char is injected into the bath providing carbon for the final reduction step. The injection creates a vigorous stirring motion which improves productivity by minimising iron oxide content in the slag. The hot metal and slag are continuously discharged from the smelter vessel bottom.

The hot off-gas leaving the furnace top is cooled in a waste heat recovery boiler. Particulates in the gas are then removed in a dry dust catcher before the gas is fed through to an incinerator in which any remaining CO or unburned carbon is combusted with oxygen. The heat generated is transferred in a second waste heat recovery boiler. De-dusting, desulphurisation and dehydration steps follow before the resulting dry CO_2 rich gas (90-95%) is processed in a separation unit leaving pure CO_2 for compression and delivery to a storage pipeline (IEAGHG 2013b), or sold for CCU applications. Pressure swing absorption or cryogenic separation is the technology favoured by the ULCOS programme (Zep 2013).

The conventional blast furnace requires a minimum rate of coke to provide sufficient physical support to the burden. The quality and strength of the coke itself must also meet the correct standard or risk an 'inactive deadman' on the hearth bottom (Raipala 2003). This harmful phenomenon can reduce hot-metal quality and campaign life, and require increased fuel rates to reactivate (ibid.). There is no deadman in the HIsarna furnace as there is no requirement for coke. As such there is also no requirement for high quality coking coals. Indeed, it is claimed that HIsarna could operate on steam coals or even biomass, i.e. charcoal (van Boggelen 2012).

The technology is expected to produce higher quality iron at reduced capital and running cost. As well as a significant reduction in energy demand, site emissions reduction is claimed to be 20% without capture and 80% with capture (van Boggelen 2012). The technology is in the pilot demonstration phase with an experimental plant at TATA Steel's Ijmuiden works in the Netherlands. This was established in 2010 and produces 8thm/d (Birat 2012, Zep 2013).

A UK HIsarna steelworks was constructed by replacing the coke oven, sinter plant, and blast furnace of the baseline integrated site with the HIsarna system, which has itself been modelled to run on coal, charcoal or any blend of the two. Energy efficiency is assumed to reduce by 5% from switching to charcoal. The existing natural and by-product gas boilers are also retired as onsite steam demand is fully met by the HIsarna waste heat boilers. The amount of steam produced is enough to meet all process needs with the remainder being put through existing and additional condenser turbines for electricity generation. Before the steam enters the turbines it is assumed that a small amount of natural gas (10% of steam input energy) is required to fuel a superheater to boost pressure. Natural gas also replaces process fuelling demand where it was previously met by blast furnace and coke oven gas. As indicated in literature (Link 2008) the pyrolysis screw is heated with the off-gas generated by its process and is thus assumed not to have a natural gas requirement. All oxygen demand is provided by an onsite ASU which operates on electricity for the site with CCS, or steam where there is no separation equipment and therefore a greater availability of steam. Where there is a greater demand for steam from amine scrubbing, less is available for autogeneration and more electricity is purchased.

4.4.4.3 ULCORED

ULCORED is a shaft based direct reduction process with an optimised design for CO_2 recovery and higher fuel efficiency. The process has been assessed with the use of syngas derived from natural gas, coal or biomass (Knop et al. 2008). Another possibility is hydrogen (ibid.) but this has not been modelled.

In the natural gas based process, syngas is produced by burning the fuel, preheated, with pure oxygen in a partial oxidisation reactor (POX), as opposed to the traditional gas reformer as used in the MIDREX system. A shift reactor is used to convert most of the CO in the top-gas of the shaft furnace to H_2 and CO_2. CO_2 can be separated using PSA, VPSA or amine separation technology (Knop et al. 2008) before compression and delivery to a storage pipeline. Most of the H_2 rich stream is mixed with natural gas and fed to the cooling zone of the shaft reactor where the latent heat of cooling is recovered to preheat the mix before being sent to the POX. Some of the stream is sent back to the shifter to be preheated before mixing with the raw POX output, forming the final preheated blend constituting the syngas.

In the coal based process, syngas is produced in a standard coal gasification unit (shell gasifier) and cleaned of dust and sulphur before use in the shaft furnace (Bergman and Larsson 2008). Some of the gas can be bypassed directly to the shifter for producing a CO_2 free gas for use in other process plant or for onsite electricity generation. The shifter can produce such a gas from coal or biomass derived inputs. In the biomass based process, syngas is produced from fluidised bed gasification technology supplied by wood chips, wood pellets or agricultural residues (Buergler and Donato 2008). The system is more energy efficient than the coal based system, though slightly less efficient than the natural gas system.

Most of the development for ULCORED is being carried out by Swerea MEFOS, Seimens VAI and LKAB (IEAGHG 2013b). An experimental pilot 1tdri/d DRI facility at Lulea in Sweden is planned (Zep 2013). A natural gas based ULCORED site with CO_2 storage has been estimated as having an 80% lower emission of greenhouse gases than the integrated site (Birat 2012).

Greenfield ULCORED steelworks sites based on natural gas, coal and biomass have been modelled. The option of deploying ULCORED at existing EAF sites is also modelled. The sites use an electric arc furnace with the same scrap input share and range as with the MIDREX site. Oxygen demand is met by an onsite ASU. Configurations with or without autogeneration were constructed. The coal and biomass options have also been modelled with excess syngas production for use elsewhere onsite. Both the amine scrubbing and VPSA based separation equipment options have been modelled. Boiler or turbine generator efficiency at coal and biomass sites may vary according to the composition of the syngas. The model includes the option to vary boiler and turbine generator efficiencies at each site.

4.4.4.4 Electrolysis

Two iron ore electrolysis methods are being developed under the ULCOS programme: ULCOLYSIS and ULCOWIN.

In the ULCOLYSIS method, iron ore is dissolved in a 1600˚C molten oxide electrolyte solution. A carbon free, inert anode with electric current is dipped into the liquid iron bath. Oxygen gas evolves at the anode and liquid iron forms at a cathode. The ULCOLYSIS method is a similar process to the molten oxide electrolysis (MOE) concept for which an initial R&D project was successfully completed in 2007 at MIT (Hasanbeigi et al. 2013). MOE is an extreme method of salt electrolysis, which has been established for over a century as the technology for producing such metals as aluminium, zinc and nickel (ibid.). The distinguishing characteristic of MOE, or ULCOLYSIS, is the use of carbon free anodes.

The ULCOWIN process, also referred to as electrowinning or alkaline electrolysis, is a process in which iron oxide particles are suspended in a concentrated aqueous alkaline electrolyte (pH15) to provide the right conditions for electrochemical reduction (Allanore 2012). The electrolysis of

suspended iron oxide particles at low temperature was patented in 1918 but only recently have insights into a cathode reaction process revealed a topochemical electroreduction mechanism for iron oxide reduction without melting (ibid.). The reaction takes place at a temperature of about 100°C.

ULCOLYSIS and ULCOWIN provide carbon free routes to producing new steel without the need for coke ovens, sinter plant or blast furnaces. The processes have an electricity demand of around 10GJ/thm on an energy supplied basis (Birat et al. 2008). Used with a decarbonised electricity source, site emissions would be close to zero. Both technologies have been demonstrated at laboratory scale under phase I of the ULCOS programme (Hasanbeigi et al. 2013). Refinement and scale up of ULCOWIN is underway as part of phase II though it may take another decade before a pilot demonstration of a comparable scale to other ULCOS technologies is possible (EUROFER 2013). The outlook for ULCOLYSIS is less promising as a suitable material for the anode has yet to have been discovered (IEA 2009c).

A UK ULCOWIN steelworks site was constructed with an EAF with metallic charge of 84% iron and 16% scrap (Birat et al. 2008). The model enables scrap concentration to be adjusted with the range 16-70%.

4.4.5 Summary

4.4.5.1 Process improvement

Figure 4-29 shows the effect on SEC of retrofitting an *additional* technology portfolio (TP) to the UK baseline sites and compares this to the BAT sites assessed in section 4.3.2. For reference, the 2007 and 2007u baselines are shown alongside. The portfolio includes: coke dry quenching; 200kg/thm blast furnace coal injection; blast furnace slag heat recovery; sinter plant main exhaust and cooler exhaust heat recovery; maximum BOFG and heat recovery; scrap preheating; and 33% thin slab casting. The BAT site shown also includes slag heat recovery and has the same uptake of thin slab casting as has TP.

The sum of all energies up to and including primary electricity is the simple primary specific energy consumption (SEC_p). NER is calculated as the sum of SEC_p, L2 process energy intensity, and L1-2 transport energy intensity. So that the defined output of the sites in terms of crude steel is unchanged, the output of the thin slab caster is measured in crude steel equivalent, which is the amount of crude steel that would have been required were the product casted for rolling. The 2007 coke production energy deficit as a proportion of coke demand is maintained.

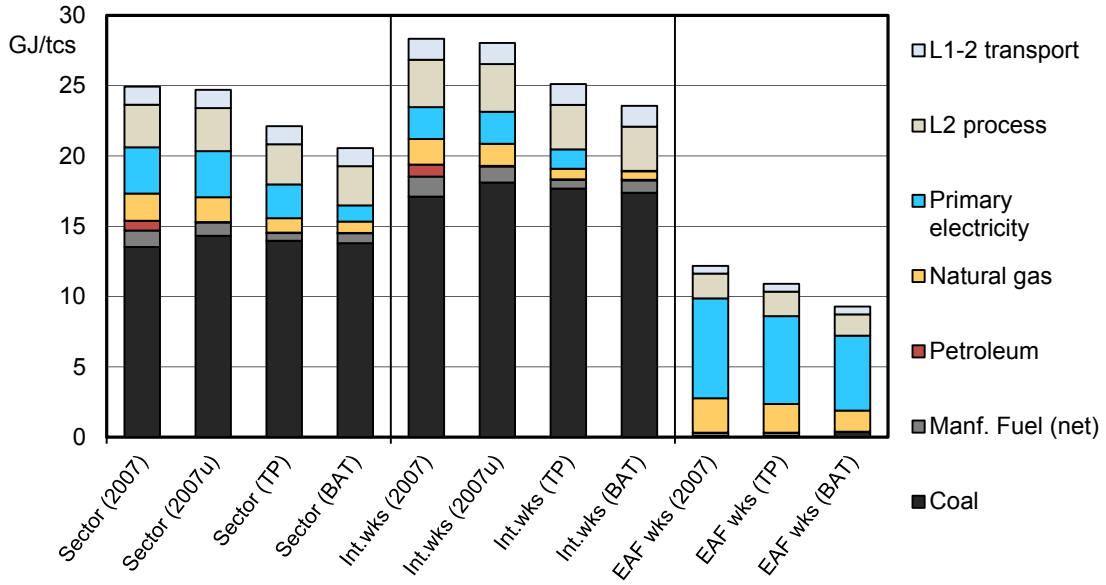

Figure 4-29: Baseline and BAT NER of the UK iron and steel sector split into sites

The applied portfolio achieves about three quarters of the technical potential indicated by the BAT sites for energy demand reduction and two thirds of the potential for GhG emissions reduction. The difference is partly made up by minor additional technologies that were not included in the portfolio, and partly due to the improvement by the BAT EAF above the improvement made by the single measure of retrofitting scrap preheaters. It was found that applying the portfolio at the integrated site required a slight increase in boiler capacity for electricity generation so as to utilise an increased surplus of by-product gases. At the BAT integrated site it was necessary to generate nearly all electricity demand in this way. In reality, such a scenario may lead to some electricity being sold to the grid.

4.4.5.2 Process and system replacement

For replacement technologies a comparison has been made with two sets of different equipment choice and configuration: set X and set Y. In set X the preferred separation technology for all capture sites (excluding the integrated site with CCS) is VPSA. DRI sites import all electricity demand except in the case of the MIDREX capture site and biomass ULCORED site with excess syngas. With the former it is assumed that additional capture from onsite electricity generation is a prerequisite to investing in CCS, and with the latter, syngas that is surplus to process needs is necessarily utilised for autogeneration. In set Y, DRI capture sites meet all of electricity demand via an onsite NCGG turbine generator with capture, excluding the amount produced via syngas at coal and biomass ULCORED sites. MDEA separation is used instead of VPSA.

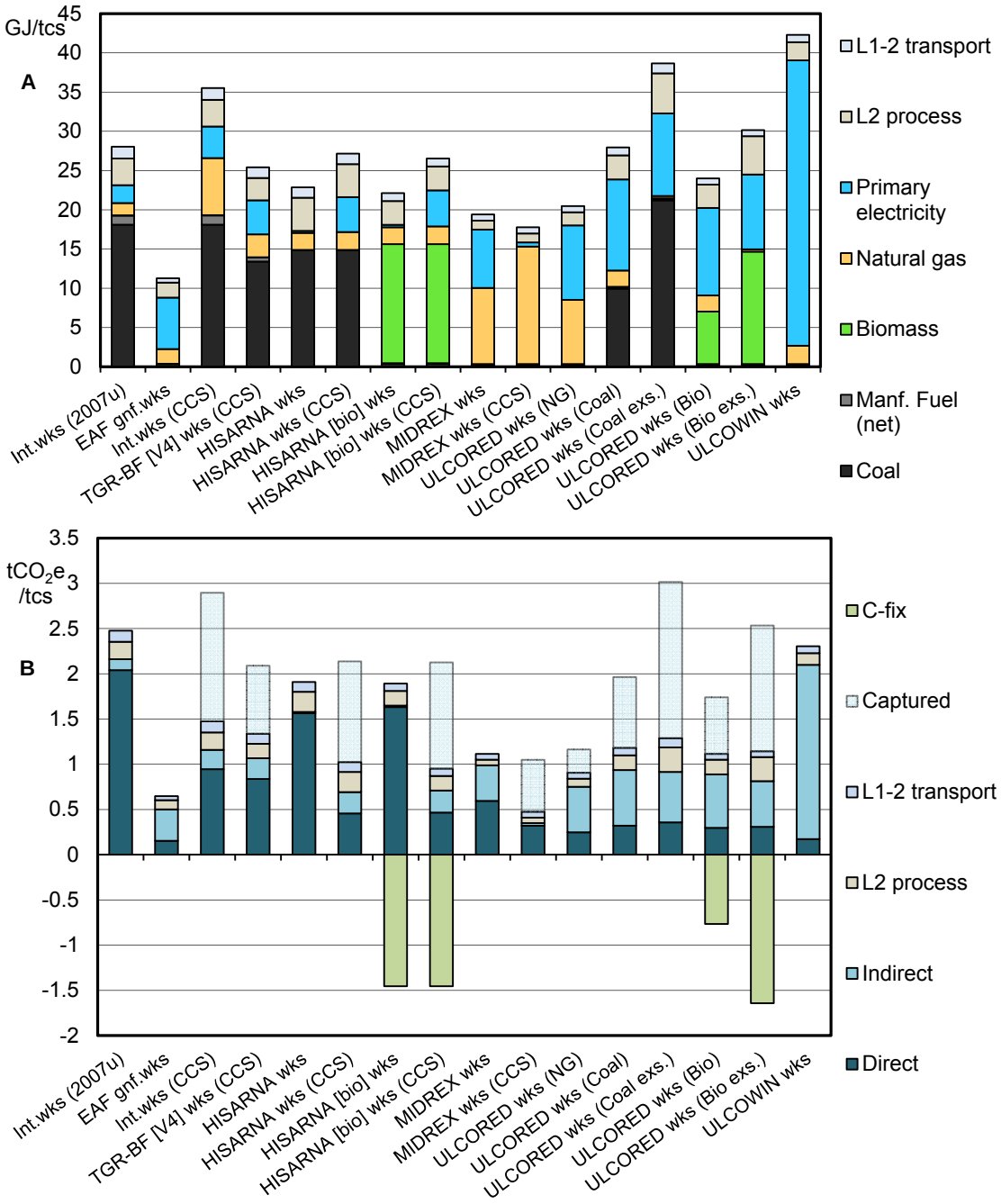

Figure 4-30: Baseline integrated site and replacement technology site NER (graph A) and NRE (graph B) for technology set X

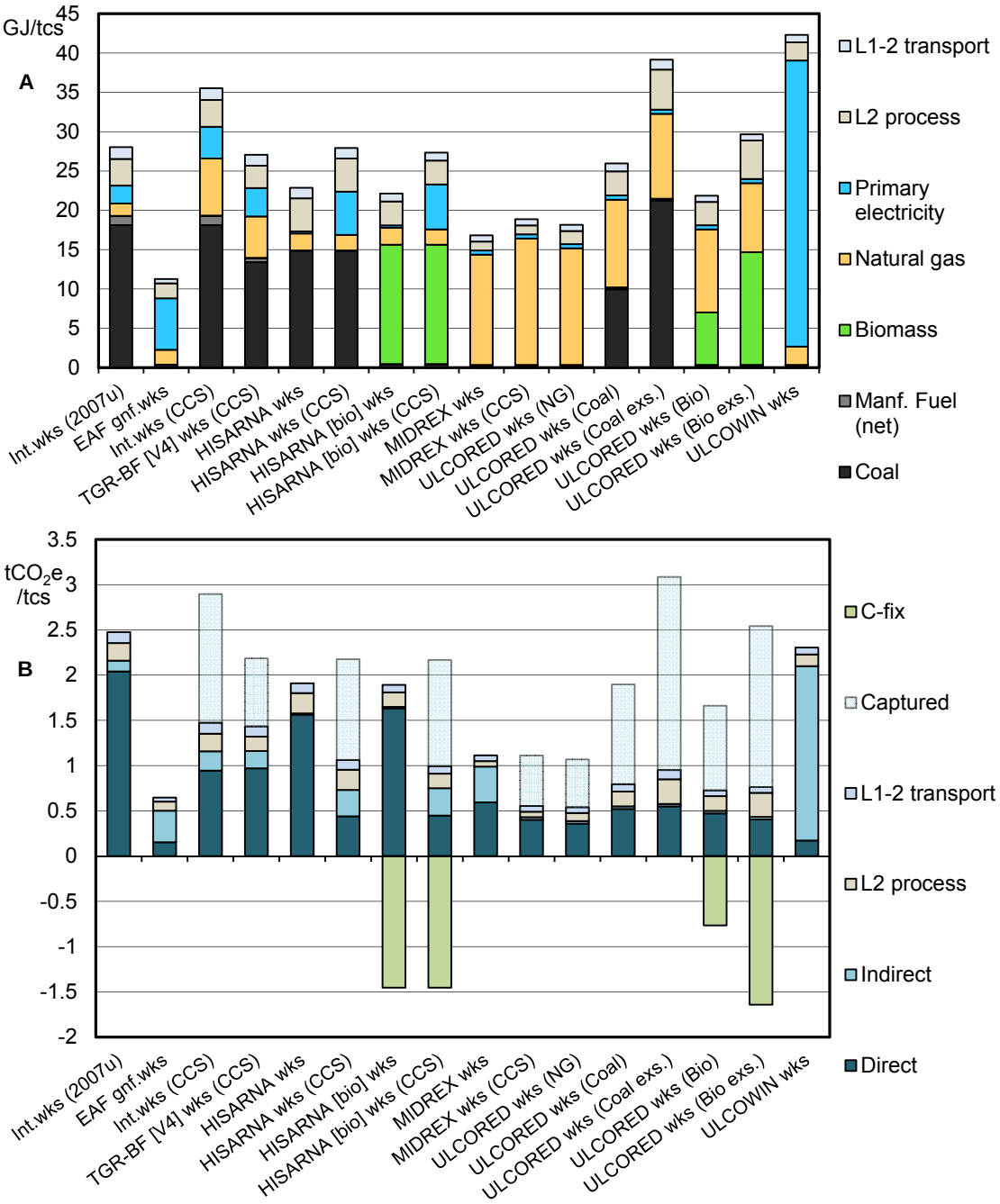

Figure 4-31: Baseline integrated site and replacement technology site NER (graph A) and NRE (graph B) for technology set Y

Figure 4-30 and Figure 4-31 compare, respectively, for set X and set Y the energy (A) and GhG (B) intensities of the baseline integrated steelworks site with that of a range of other sites incorporating the identified existing and future replacement technologies. All sites were constructed for replacing the integrated site with casting, hot-rolling, downstream and other activities unaffected, except for process fuel mix which is inevitably subject to change.

The EAF site is Greenfield and incorporates process plant modelled for the ULCOS project (Birat et al. 2008). All other replacement sites shown are Brownfield in that the replacing technologies were modelled into the UK baseline with the performance of all other plant unchanged. The C-fix emissions are shown and would lead to some sites becoming carbon negative as more carbon is taken from the atmosphere and stored than is emitted. Direct emissions are lower for the excess bio-syngas site because a higher proportion of energy demand is met by carbon free syngas. It should be considered that scope 2/3 GhG emissions are subject to significant reduction in the future. This would have the greatest effect on the ULCOWIN site and favours technology set X.

It is also noted that a minimum purchase of grid electricity remains after autogeneration to reflect the UK sector structure in which some downstream finishing activities occur off-site and so have been modelled not to use electricity from the generating plant. For energy and emissions intensity of the full range of site configurations and equipment choices, refer to section A5.9, Figure A-35, and Figure A-36 of the Appendix.

4.5 Techno-economic roadmap assessment

In this section a techno-economic roadmap assessment is conducted for the potential deployment of identified technologies out to 2050. The extent of resource demand and GhG emissions reduction is therefore quantified and investigated alongside the economic implications of achieving them. Illustrative and optimised 2050 roadmaps are designed to explore a range of possible technological pathways for the sector. Technology set X, defined above, has been chosen for this assessment.

4.5.1 Roadmap modelling

A number of other studies have modelled iron and steel sector futures. The European Commission's Joint Research Centre (JRC) produced the ISIM model to simulate production and consumption of steel, energy demand and CO_2 emissions over the period 1997-2030 (Hidalgo et al. 2005). New and retrofit technology routes were assessed but from a top-down perspective with limited detail. Moreover, technologies incorporating CCS were not included and the assessment preceded developments associated with the ULCOS programme.

Over the past few years focus has shifted to the development of bottom-up technological modelling (EUROFER 2013). In 2012 the JRC published such a study assessing the impact on the European iron and steel sector of technology diffusion out to 2030 (European Commission 2012c). The assessment is reasonably transparent in terms of assumptions on process performance and the economics of plant and resource flows. However, the time horizon of the study is inconsistent with the expected course of development of key technology options assessed including CCS.

In 2013 the Boston Consulting Group (BCG) and the Steel Institute VDEh produced a bottom-up assessment of the European iron and steel sector out to 2050 (BCG 2013). The study was commissioned by EUROFER, who elaborate on the findings in their publication 'A steel roadmap for a low carbon Europe 2050' (EUROFER 2013).

The BCG/VDEh study does not state many of the assumptions used in its model simulations nor does it disclose critical variables, e.g. fuel and feedstock prices. Moreover, technologies are compared by their steelmaking process routes (to the level of hot-rolling) with consideration of steam and power generating plant, or other ancillary plant such as onsite oxygen production, omitted or accounted for with simplifying assumptions. Key breakthrough technologies such as HIsarna, ULCORED, and ULCOWIN were also omitted from the analysis.

4.5.2 Techno-economic roadmap projection model

For this assessment a bottom-up techno-economic roadmap projection model was built in Microsoft Excel. The model is flexible, data-rich, and fully transparent. This is to enable future

assessment with different scenarios and assumptions, and to ensure that the present assessment can be fully scrutinised and reproduced. Further details of the model and key assumptions used in the present assessment are provided in sections A5.6 and A5.5 of the Appendix respectively.

The resource balances and economics of the sites (section A5.11.2 of the Appendix) were incorporated into the model so that key variables are brought into control. Figure 4-32 is a screenshot of the control interface for selected variables. A global lifetime for sites is applied with a suggested range of 25-40 years. However the model does enable assessment to be switched to a selection of site-specific discount rates and lifetimes. The option to adjust the difference in capital cost of refurbishing a technology over replacing anew is also given for key equipment as this has been perceived as a variable of potentially significant uncertainty. The proportions applied were based on those used by BCG (2013) in their 2050 roadmap.

The baseline can be switched between 2007 and 2007u. BAT definition may be adjusted here to include slag heat recovery and up to 33% thin-slab casting. The scrap share in metallic charge to the EAF of ULCOWIN and DRI sites may be adjusted. The HIsarna site equipped with CO_2 separation (site 8) may be used to store CO_2 or not. The same option is available for the TGR-BF site through the choice between sites 5 and 6. If the CO_2 is not stored it may be sold at a given price. The effect of CCU options in terms of abatement can be adjusted for by applying a percentage of abatement to the captured CO_2. The price of CO_2 for emissions trading is separate from the sale price and it may be specified whether or not the emissions associated with electricity purchases are included. A site would best improve the payback from CO_2 capture if the CO_2 is sold and sold to an application that is avoiding its emission, or other emissions, and thereby minimising emissions costs.

The cost to the industry from the EUETS only applies to emissions counted for trading within the system. This excludes non-CO_2 GhG emissions and emissions associated with various minor activities. The option of specifying the trading price to all emissions or just tradable emissions is given. Tradable GhG emissions were calculated for all sites as CO_2 emissions for all activities excluding 'downstream and other'. This was shown for the baseline in section 4.2.3.1 to account for about 90% of sector GhG emissions. It was also shown to align very closely with emissions verified under phase II of the scheme.

Biomass may be used to fuel the HIsarana process and the option of switching to any proportion of coal and charcoal is given here. The option of biomass carbon fixation is also given. Modifying the emissions factor of biomass or any other resource, however, is done in the parameters worksheets of the model (section A5.10 of the Appendix).

Variable	Input	Suggested	Other OPEX suggested	Unit /choice	Notes
Variable OPEX flows					
CO_2 trading price	0	0	100	£ per tonne	
CO_2 sale price	0	0	50	£ per tonne	
Iron ore price	56.57	56.57	91.15	£ per tonne	
Finishings	1,132	1,132	1,824	£ per tonne	
Coking coal price	119	119	225	£ per tonne	
Coal price	65.46	65.46	124	£ per tonne	
Scrap price	147	147	237	£ per tonne	
Natural gas price	1.64	1.64	3.63	pence per kWh	
Biomass price	236	236	236	£ per tonne	
Charcoal price	106	106	106	£ per tonne	
Electricity price	5.96	5.96	8.20	pence per kWh	
O2 price	0.06			£ per Nm3	Linked to electricity
Price only tradable CO_2?	Y	Y		Y/N	
Include elec in CO_2 price?	N	N		Y/N	
Flat price	N	N		Y/N	
Other techno-economic variables					
Load factor	90%	90%		%	Nameplate capacity load factor
Global discount rate?	Y	Y		Y/N	
Discount rate	10%	10%		%	
Global technology lifespan?	Y	Y		Y/N	
Lifespan	25	25		Years (15-40)	
Ramp-up capacity?	Y	Y		Y/N	
Ramp extent	100%	100%		%	
Greenfield only?	Y	Y		Y/N	
Retrofit/Greenfield plant cost					
Coke oven	15%	15%		%	
Sinter plant	30%	30%		%	
Blast furnace	50%	50%		%	
Basic oxygen furnace	50%	50%		%	
Electric arc furnace	50%	50%		%	
Other plant	50%	50%		%	
Additional technical variables					
Updated 2007 baseline (2007u)?	Y	Y		Y/N	
33% thin-slab casting	100%	100%		% (0-100)	
Slag heat recovery?	Y	Y		Y/N	
TGR-BF coke rate	259	259		187-259kg/thm	Minimum total fuel rate, 367kg/thm
TGR-BF coal injection rate	152	152		152-180kg/thm	Minimum total fuel rate, 367kg/thm
DRI scrap level	40%	40%		% (30-70)	
ULCOWIN scrap level	16%	16%		% (16-70)	
Biomass C-fixation	Y	Y		Y/N	
HISARNA w/ sep. - CO_2 storage?	Y	Y		Y/N	
Bio-HISARNA?	N	N		Y/N	
% charcoal subs.	100%			% of fuel energy input	
Effective CCU emissions abatement	0%	67%		% of capture (0-100)	
Equipment capture efficiency					
RETROFIT	85%	85%		%	
TGR-BF	90%	90%		%	
HISARNA	90%	90%		%	
MIDREX	85%	85%		%	
ULCORED	90%	90%		%	
Boiler/generator efficiency					
Coal syng. boiler efficiency	80%	80%		%	
Bio.syng. boiler efficiency	80%	80%		%	
Coal.syng. turbine efficiency	45%	45%		%	
Bio.syng. turbine efficiency	45%	45%		%	

Figure 4-32: Screenshot of iron and steel techno-economic projection model variable control interface

The integrated steelworks site is an interconnected system with a myriad of potential conflicts and synergies that can arise from changing individual process plant and equipment. Therefore, bringing control to the uptake of individual technologies beneath the site level would require an advanced system model. Such a model would require specialised software and thus compromise reproducibility. Instead choice is given between 16 distinct sites of which penetration is the site's

production of crude steel as a percentage of the total sector output. If a technology is to be retrofitted to the existing structure, this is modelled where only that technology distinguishes the replacement site. The replacement site has incorporated into it the site-level effects of that technology. These effects inevitably include some level of fuel switching at the process plant level such that the use of by-product gasses, steam and autogenerated electricity has to be redesigned and rebalanced.

The uptake of BAT and substitution of iron with scrap at the BOF is modelled in a similar way. For each site a BAT sister site has been designed by reconstructing it with all available BAT plant and equipment. The penetration of BAT is then the extent to which the site is supplanted by its BAT counterpart. For sites with a BOF, another counterpart is designed by reconstructing it for a maximum (35%) input of scrap. The base and BAT sites each have BOF scrap counterparts which supplant them equally and simultaneously. Thus, the selected level of scrap substitution between the base site and the BAT sister site is maintained for any penetration of BAT. Each site has been assigned an identification number and the full range of sites and alternative configurations is listed in Table A-18, section A5.8 of the Appendix.

Figure 4-33 displays the interface enabling the construction of roadmaps with 5 year intervals to 2050. The model begins at the model base year (2007) from which site share and aggregate production has been updated annually to 2013. The chosen base year for the projection analysis is 2010. Cells shaded in grey for uptakes are editable but this is not suggested for the generation of roadmaps as they reflect assumed technological unavailability or years past. The grey cells above the uptake % rates for "Y", i.e. yes, inputs have not been modelled for and so are unresponsive.

Choice is given at some sites between amine scrubbing and VPSA separation technology. Choice between Greenfield and retrofit for certain technologies is also given. It is assumed that any future deployment of HIsarna or TGR-BF would occur within existing integrated steelworks. However, MIDREX, ULCORED and ULCOWIN may be either Greenfield sites or deployments at existing EAF sites. The Greenfield option replaces production at the base integrated site (1) and the retrofit option must replace production at the base EAF site (2). The user may also decide whether the DRI sites import or generate electricity. The exception to this is the MIDREX CCS site as it is assumed that it would only be viable to apply CCS at the MIDREX site if emissions from an onsite electricity supply were also captured. Conversely, ULCORED is designed for efficient capture and so is assumed viable without onsite capture. It should be noted that some electricity is still generated at the electricity import configurations of sites 13 and 15 because the production of syngas surplus to process requirements is utilised for this.

Iron and steel roadmap design interface																							
	Sub site level		Substitutional																		External		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
Year	BAT uptake	35% BOF scrap	Int.wks (Base)	EAF wks (Base)	EAF gnf.wks	Int.wks (CCS)	TGR-BF wks (CCU)	TGR-BF wks (CCS)	HIsarna wks w/o sep.	HIsarna wks (CCS)	MIDREX wks	MIDREX wks (CCS)	ULCORED wks, NG (CCS)	ULCORED wks, coal (CCS)	ULCORED wks, coal w/exs syng. (CCS)	ULCORED wks, bio (CCS)	ULCORED wks, bio w/exs syng. (CCS)	ULCOWIN wks w/o autogen.	Grid primary energy intensity change	Grid decarbonisation	2007 prod.
	VPSA = Y						Y	Y		Y		Y	Y	Y	Y	Y	Y				
	Greenfield = Y										Y	Y	Y	Y	Y	Y	Y	Y			
	Elec. import = Y										Y		Y	Y	Y	Y	Y				
2007			79%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
2008			78%	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	1%	94%
2009			79%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	70%
2010			76%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	3%	67%
2011			74%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	66%
2012			79%	21%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	7%	67%
2013			84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	8%	82%
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	13%	83%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	26%	83%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	46%	83%
2030	55%	15%	78%	16%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	59%	83%
2035	67%	20%	64%	16%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	69%	83%
2040	67%	25%	37%	16%	7%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	75%	83%
2045	67%	33%	26%	16%	11%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	80%	83%
2050	67%	41%	14%	16%	14%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	85%	83%

Figure 4-33: Screenshot of iron and steel techno-economic projection model roadmap construction interface

Variables characterised as external to the sector such as grid efficiency and decarbonisation are controllable. Aggregate sector production is also included and categorised as an externally affected variable. Wherever the cause derives, the model allows for any possible structure and size of sector to be created from the identified technology options. The effect of more encompassing measures such as material efficiency may therefore be assessed. For example, the general effect of improved steel quality, dematerialisation and design for longevity or reuse is a reduction in the demand, and therefore production, of steel.

In reality, however, the effects of material efficiency in consuming sectors go wider than steel production in the UK and would be better associated with UK consumption, which would include the import of steel produced in other countries. Imported steel may be represented by ascertaining the share of production between the integrated site, the EAF site and the MIDREX site of the imported countries (and potentially other sites in future scenarios). Imports from individual countries can then be aggregated up. If the electricity supply is less efficient in the exporting country then this can be represented with negative values of decarbonisation percentage. However, the model's minimum baseline efficiency is that of the UK, i.e. 2007 baseline with 0% progression towards BAT. So adjustment factors would need to be introduced to account for less efficient exporters.

4.5.3 Baseline projections

The this roadmap assessment the baseline is adjusted for future years based on forecasts of steel production, scrap availability, and grid related energy and emissions intensity. The status of plant and equipment efficiency as is separate from the action of replacing processes is also taken into consideration. The future influence of grid efficiency and energy mix is relevant to all industrial sectors and is analysed in section A4 of the Appendix. It is assumed that the grid will decarbonise by 85% over the period 2010-2050.

4.5.3.1 Crude steel production

Production forecast is based on a steel intensity curve method used in the BCG/VDEh study (BCG 2013). Figure 4-34 is a graph which shows crude production and consumption intensity (steel/GDP) against national affluence (GDP/capita). Crude steel production figures begin in 1926 and apparent steel use (consumption of finished steel industry products) figures begin in 1960. As steel intensity peaked in 1960, the steel intensity curves begin in that year.

Over time the general trend in crude steel production has converged towards the level of apparent steel use. With a conversion rate of around 90%, finished steel deriving from crude steel production is approximately equal to apparent steel use. For simplification it is assumed that the UK will remain this way, i.e. as an effectively 'self-sufficient' consumer of finished steel. The

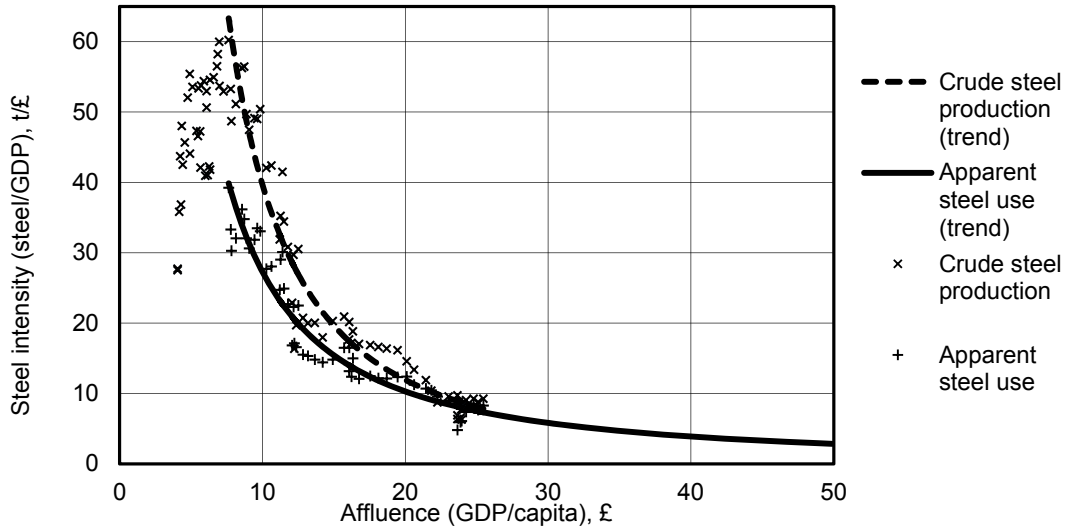

Figure 4-34 : Steel intensity curves of the UK iron and steel sector

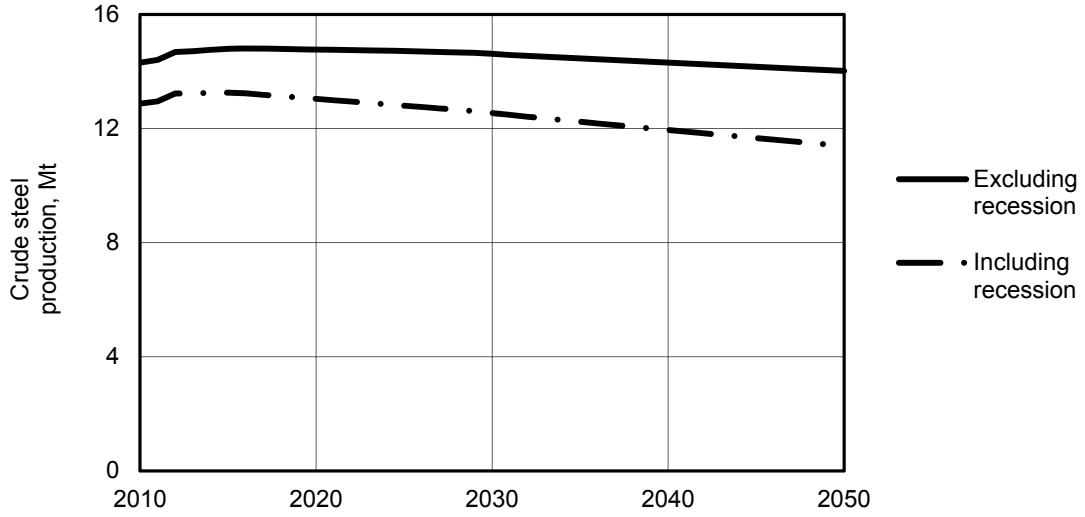

Figure 4-35 : Projected crude steel production from the UK iron and steel sector

projected apparent steel use is calculated by multiplying the extrapolated steel intensity with the forecasted growth in GDP (DECC 2013e, OBR 2013).

Using curves based over the period to 2013 includes the recent dip in production relating to the recession. However, because the fall in production was mostly unaccompanied by a fall in production capacity, it may be viewed as transitory. Indeed, with return to reasonable production in 2013 and an even higher production so far in 2014 (World Steel Association 2014a, 2014b), the sector is showing recovery. Figure 4-35 shows the projected production of crude steel based on steel intensity curves for the period 1960-2007 (excluding recession) and 1960-2013 (including recession). The former period yields a fairly stagnant future production rate whereas the latter yields a declining future.

Based on the steel intensity curve which excludes the recent dip in output, future crude steel production for the roadmaps is assumed to be stagnant. The trend is also assumed to project from a base of 12Mtcs, reflecting the present condition of the sector. This output roughly equates to 75% of capacity, which might be deemed conservative but takes into consideration the sensitivity of production to resource price shocks and the wider economy.

4.5.3.2 Scrap consumption

It is widely viewed that availability of scrap for steelmaking in Europe and globally is likely to increase over the period to 2030 and to 2050 (BCG 2013, European Commission 2012c, IEAGHG 2013b, Laplace Conseil and EFR 2013). Scrap derives from three sources: obsolete scrap, largely emanating from infrastructure and product turnover; prompt scrap, raised from steel consuming manufacturing industries e.g. automotive cut-offs; and home scrap, arising from within the iron and steel sector.

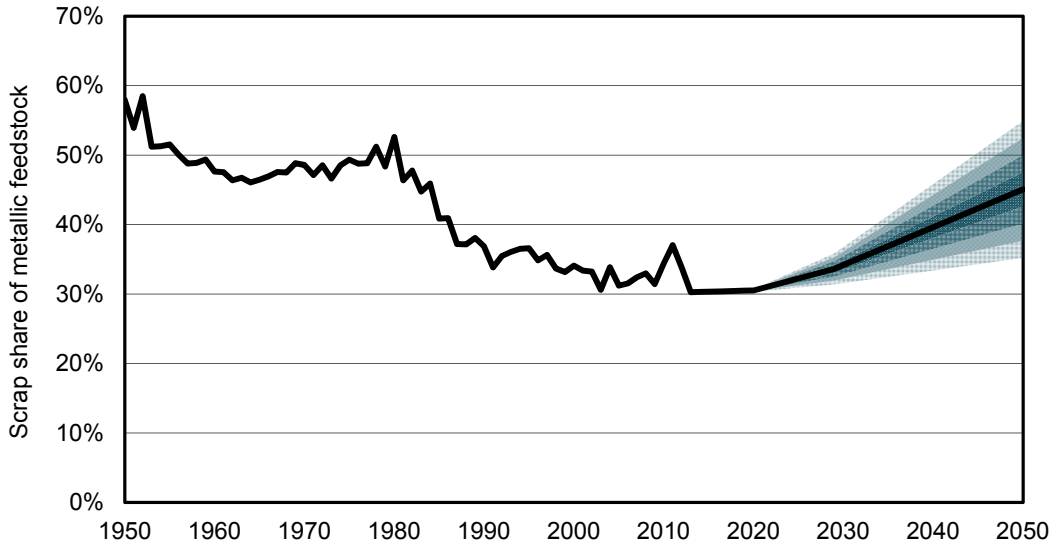

Figure 4-36 : Projection range for average scrap share in metallic charge in the UK iron and steel sector, 2014-2050, and historical share over the period 1950-2013

Home and prompt scrap generation in the UK is low compared with obsolete scrap arising and has reduced significantly over the past 40 years from conversion efficiency increases and deindustrialisation. The future availability of prompt scrap will increase if projected economic growth is not accompanied by a compensatory rate of continued deindustrialisation and material efficiencies elsewhere. Regardless, the additions to total scrap arising from this source would be marginal.

The main increase in scrap availability would come from obsolete scrap. A boost in construction scrap in Europe originating from the 1960s boom is expected by BCG and the Steel Institute VDEh from 2020 (BCG 2013). This would be additional to the EU's 2.5Gt scrap stockpile which is increasing at a rate of 20Mt per year (Laplace Conseil and EFR 2013). While Europe

appears in no shortage of scrap, the global scrap market has been predicted to grow considerably in the next 30 to 40 years driven by obsolescence in China, and later India, possibly reducing global BOF/EAF share from 70/30 to 50/50 (IEAGHG 2013b).

A key issue is how this would affect the balance of scrap trade in the UK. Scrap trade in Europe divides into three regions: Northern Europe, Southern Europe, and Central Europe (Laplace Conseil and EFR 2013). Northern and Southern Europe account for 85% of European crude steel production (World Steel Association 2013). Northern Europe is a net scrap exporter and produces steel with a BOF/EAF share of 70/30 while Southern Europe, which grew its industry later than Northern Europe, with a share of 30/70 is a net scrap importer. The UK is consistently the largest single net exporter of scrap in Europe (ibid.) and in 2013 had a BOF/EAF share of 84/16. As a proportion of crude steel production the UK's net export of scrap is typically around 60-70%, compared with just 15% for Northern Europe as a whole.

Based on this arrangement, the UK is most at risk from a reduction in scrap price associated with increased regional and global availability. In such a case, demand for export would reduce and it may make economic sense to increase domestic consumption of scrap. If half the export level in 2013 was affected, the UK sector could produce steel with a BOF/EAF share of 60/40 and a BOF scrap input of 25% metallic feed (or a 50/50 share with a BOF scrap input of 15%). This is equivalent to a 2.2% annual increase in scrap consumption over a 40 year period and would be feasible by maintaining present production with two, instead of three, integrated steelworks.

It is proposed here that scrap consumption in the UK will increase annually by an average of 0.44-2.2% (mean 1.3%) over the period to 2050 and that this increase will become steeper after 2030. The lower boundary is equivalent to increasing scrap consumption by 10% of the amount exported in 2013. This projection is shown in the context of historical scrap use in Figure 4-36.

4.5.3.3 Baseline efficiency

All sites progress with the uptake of improved ancillary plant and equipment. This is defined here as the level of uptake of BAT. The effect of a major replacement technology will be influenced by the BAT level at the time. This introduces the concept of baseline efficiency against which the potential of disruptive replacement technologies should be measured. For example, the potential of a new HIsarna smelting furnace is lowered if it displaces state-of-art coke-dry-quenching batteries, heat recovery equipped sinter plant and a well-run blast furnace with high coal injection rate. The same logic applies to the effect of substituting iron with scrap at the BOF and the effect of grid decarbonisation is also curbed by the use of scrap preheating at the EAF.

4.5.4 Future technological economics

Before constructing roadmaps it is useful to understand the economics of individual sites. Table 4-10 summarises site abatement economics for the baseline and replacement technologies. The annual production cost, or break-even price, per tonne of crude steel for each site is calculated from a discounted cash flow analysis over a 28 year project life (25 year production life). The difference in production cost compared with the replaced baseline per tonne of GhG emissions avoided, or abated, is the abatement cost. For more detail on costs and abatements, including of different site configurations, refer to section A5.9 of the Appendix.

The baseline sites are the integrated steelworks (1) and the EAF steelworks (2). No replacement sites have been identified for the EAF steelworks meaning that sites 3-16 have the integrated steelworks as their baseline. The EAF works is, however, is subject to process improvements towards the BAT level. The approximate error in the calculation of production cost, based on uncertainty for all key capital and variable costs (excluding carbon trading price) is shown in the final column.

Abatement economics are presented under 'present static' and 'dynamic future' regimes. Under the present static regime, all resource prices are fixed at the 2010 level and the 2010 grid emissions factor is applied. This reflects the approach taken in existing techno-economic literature for industrial technologies (IEAGHG 2008, 2013a). Under the future dynamic regime, production begins in 2030 with changes in resource prices and grid emissions factor incorporated. The electricity supply decarbonises as described in the last section and the price of energy and material flows have been adjusted according to Table A-17 in section A5.5 of the Appendix. Presumed changes in BOF scrap and process efficiency towards BAT level are also included. Specifically, this is a 67% move towards the BAT level and a 40% move towards maximising BOF scrap input (i.e. from 15% to 23% of metallic charge), which applies to sites 1 and 4-8. Grid, BOF scrap, and efficiency changes are averaged over the production life, thus giving the average annual specific abatement for each technology. Greenfield sites are not subject to further process efficiency improvement.

Future economics under a carbon trading price is also presented. The price increases from 50 to 100£/tCO_2 over the 2030-2050 period with the trend continuing beyond 2050. This follows the lower boundary of price range suggested by DECC (2011b) for use in futures modelling, which is 100-300£/tCO_2 in 2050. Carbon fixation from biomass growth is assumed here as it is included in official Government guidelines for emissions accounting (AEA 2012).

ID	Description	Present static (2010)						Future dynamic (beginning 2030)						2030-2050 C trade price: 50-100£/tCO_2			Prod. cost +/- error pct.
		CAPEX, £/tcs	OPEX, £/tcs	Prod. cost, £/tcs	SE_2, $kgCO_2e$/tcs	Ab. pct.	Ab. cost, £/tCO_2e	CAPEX, £/tcs	OPEX, £/tcs	Prod. cost, £/tcs	SE_2, $kgCO_2e$/tcs	Ab. pct.	Ab. cost, £/tCO_2e	OPEX, £/tcs	Prod. cost, £/tcs	Ab. cost, £/tcs	
0	Sector (Base)	311	329	365	1824	-	-	378	430	454	1532	-	-	551	558	-	30%
1	Int.wks (Base)	345	339	379	2160	-	-	417	444	472	1883	-	-	594	601	-	30%
2	EAF wks (Base)	183	291	312	561	-	-	231	378	387	217	-	-	390	397	-	27%
3g	EAF gnf.wks	472	339	401	501	77%	13	494	452	499	206	89%	16	464	509	-55	27%
4	Int.wks, MEA sep.	576	387	454	1169	46%	75	617	506	553	767	59%	72	564	603	2	30%
5.v	TGR-BF wks, VPSA sep. w/o storage	443	342	393	1977	9%	75	504	448	487	1631	13%	59	575	596	-19	33%
6.v	TGR-BF wks, VPSA sep.	443	342	393	1224	43%	15	504	448	487	907	52%	15	517	546	-56	33%
7	HIsarna wks	507	252	311	1577	27%	-117	542	334	383	1480	21%	-221	453	484	-288	37%
8.v	HIsarna wks, VPSA sep.	639	283	357	692	68%	-15	670	371	433	456	76%	-27	404	461	-98	37%
7.2	HIsarna [bio] wks	507	501	560	867	60%	140	542	553	605	146	92%	77	564	615	8	50%
8.2v	HIsarna [bio] wks, VPSA sep.	646	533	608	-70	103%	103	677	591	657	-935	150%	66	512	590	-4	50%
9g.i	MIDREX gnf.wks, imp.elec.	788	312	413	984	54%	28	788	435	517	675	64%	37	482	558	-35	33%
10g.v	MIDREX gnf.wks VPSA sep.	1007	302	430	328	85%	28	1007	436	543	305	84%	45	460	564	-23	37%
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	835	313	419	726	66%	28	835	430	519	336	82%	31	449	535	-42	40%
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	964	321	444	911	58%	52	964	429	536	433	77%	44	453	557	-30	40%
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	1227	339	495	882	59%	90	1227	456	595	473	75%	87	485	620	14	40%
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	946	419	542	98	95%	79	946	512	621	-361	119%	66	472	586	-6	50%
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	1190	549	704	-866	140%	107	1190	632	775	-1230	165%	97	525	681	26	50%
16g	ULCOWIN gnf.wks, imp.elec.	896	464	579	2069	4%	2182	896	610	705	570	70%	177	622	715	87	40%

Table 4-10: Summary of abatement economics for baseline and future sites of the UK iron and steel sector

It may be observed that future abatement cost is subject to the opposing effects of an improving baseline and increasing fuel prices. An improving baseline is a relative improvement for the integrated site (1) because HIsarna and TGR-BF sites (5-8) leave less opportunity for process efficiency, e.g. from CDQ, and the Greenfield sites (3, 9-16) already incorporate updated process efficiency. Moreover, BOF scrap increase at the baseline site is more effective in that it substitutes conventional blast furnace iron. Increasing fuel prices favour processes with lower energy intensity but do not favour higher users of natural gas and electricity, for which prices are projected to increase at a steeper rate than coal. In particular, MIDREX sites and the natural gas based ULCORED system (9-11) become more expensive at abating emissions. Conversely, the coal-based HIsarna site (7, 8) reduces in abatement cost significantly as its energy input is dominated by coal and most of its electricity demand is met via a waste heat recovery system. However the largest reduction in abatement cost occurs for the ULCOWIN site (16) despite of, and because of, its high electricity intensity; though electricity price increases faster than the price of most fuels, electricity supply is significantly decarbonised.

It can be deduced that operational cost has a significant effect on production cost. For example, the capital investment required for a Greenfield coal-based ULCORED site (12) is two thirds over the cost of a refurbished and retrofitted integrated capture site (4). Yet because it has a 20% lower operating cost and production cost is also lower. Switch to a biomass-based ULCORED system (14, 15), and production cost becomes significantly higher. Indeed, the impact on the production cost of HIsarna from switching to charcoal (7.2, 8.2) is large, despite a similar capital cost. The cost of biomass for syngas gasification and the cost of charcoal are assumed equal per unit of energy. This cost is over three times that of coking coal in 2030 per unit of energy, and more than twice the expense in 2050. High uncertainty (75%) is also applied to the cost of biomass fuels to reflect uncertainty in the development of its market and the variability in biomass feedstock and production method. Hence, sites which use biomass have higher production cost uncertainty.

Generally, most options have negative abatement cost under the projected emissions trading price. Coal-based HIsarna, however, stands out as the only clear choice of economic benefit in the absence of a carbon price. This is owed mainly to improved system efficiency combined with the potential for using cheap grade coal over coking coal. However, further economic benefit can be sought through process efficiency measures. The coal and coke rates assumed for the TGR-BF technologies are 152kg/thm and 259kg/thm respectively. These are conservative compared with the ULCOS V4 configuration, which has rates of 180kg/thm and 187kg/thm respectively. Furthermore, in the absence of CCS the CO_2 extracted from TGR-BF and HIsarna sites may be sold for applications in other industries. These may include CCU applications in which GhG emissions are avoided.

ID	Description	Present static (2010)			Future dynamic (beginning 2030)			2030-2050 C trade price: 50 -100£/tCO_2e	
		Prod. cost, £/tcs	SE_2, $kgCO_2e$/tcs	Ab. cost, £/tcs	Prod. cost, £/tcs	SE_2, $kgCO_2e$/tcs	Ab. cost, £/tcs	Prod. cost, £/tcs	Ab. cost, £/tcs
1	Int.wks (Base)	379	2160	-	472	1883	-	601	-
5.vu	TGR-BF wks, VPSA sep. (0% CCU)	355	1977	-130	451	1631	-85	560	-163
5.vu	TGR-BF wks, VPSA sep. (67% CCU)	355	1475	-35	451	1148	-29	526	-101
5.2.vu	TGR-BF [V4] wks, VPSA sep. (0% CCU)	348	1818	-92	440	1475	-79	538	-154
5.2.vu	TGR-BF [V4] wks, VPSA sep. (67% CCU)	348	1317	-37	440	992	-36	504	-108
6.2.v	TGR-BF wks [V4], VPSA sep.	385	1066	6	476	750	3	524	-68
8.vu	HIsarna wks, VPSA sep. (0% CCU)	301	1805	-220	380	1528	-260	481	-336
8.vu	HIsarna wks, VPSA sep. (67% CCU)	301	1063	-71	380	813	-86	432	-157
8.2.vu	Hisarna [bio] wks, VPSA sep. (0% CCU)	549	1104	161	601	195	76	611	6
8.2.vu	Hisarna [bio] wks, VPSA sep. (67% CCU)	549	321	92	601	-558	53	559	-17

Table 4-11: Abatement economics of alternative future site configurations in the UK iron and steel sector

Table 4-11 summarises an additional group of options incorporating the improved TGR-BF fuel rate and CO_2 sale with and without CCU. CCU applications vary in their effectiveness at avoiding emission (ibid.) and a rate of two thirds is assumed here as reasonable to illustrate potential. An industrial sale price of 50£/tCO_2 is applied.

All coal-based configurations have near- or below-zero abatement cost in the absence of a carbon emissions trading price. With the trading price included, charcoal HIsarna options also become similarly economic. Though the future price for biomass is highly uncertain, it may be possible to operate HIsarna on a blend of coal and biomass. This would provide flexibility to respond to fuel and carbon price changes.

4.5.4.1 Abatement cost curves

The above figures may be visualised through AC curves. A comparative AC curve for all measures and sites under the present static regime is shown in Figure 4-37. In reality only one or a few replacement technologies could be expected in the future which is why a comparison between alternatives, as opposed to the cumulative effect of a portfolio of additive options, i.e. MAC curve, is more presentable. All key options and the base integrated site (1) have an equal share (6%) of original crude steel production from the base integrated site. The error-bars are based on production cost uncertainty and represent a proportion of the abatement cost.

Figure 4-38 compares the abatement options under the future dynamic regime. BAT and BOF scrap measures at the baseline sites are absent as they have become the baseline. The increase in reduction from the baseline is partly influenced by a general electrification of the sector coupled with grid decarbonisation.

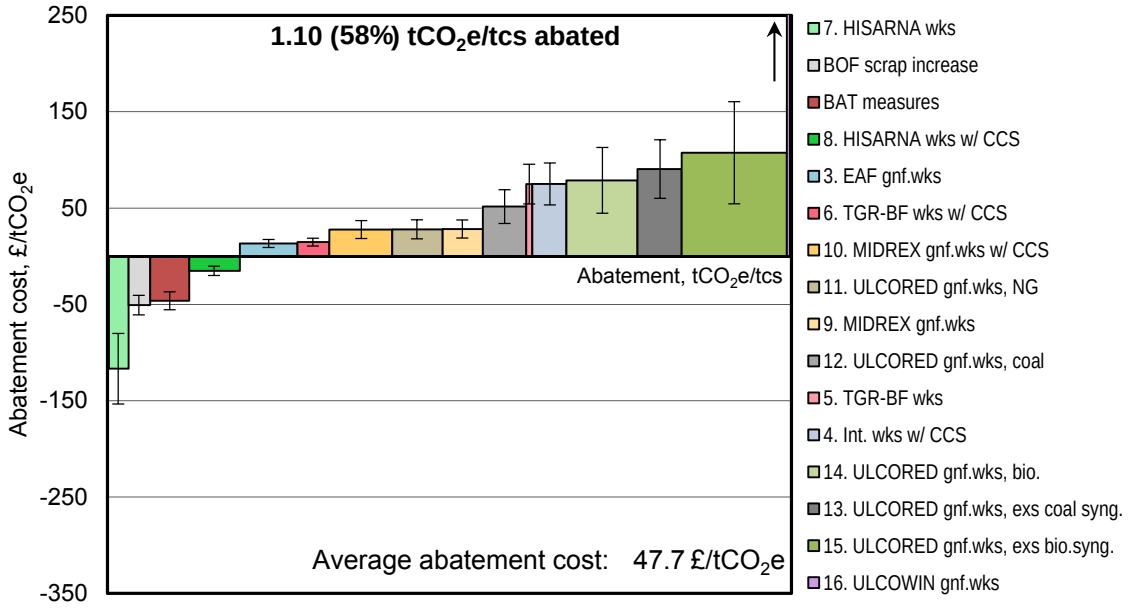

Figure 4-37: Comparative AC curve of abatement options in the UK iron and steel sector under the present static regime

Figure 4-39 and Figure 4-40 compare the abatement options under the future dynamic regime and 2050 emissions trading price of 100£/tCO_2 and 200£/tCO_2 respectively. Average abatement cost reduces considerably and all options become economic with the higher trading price. Because of their high intensity of relatively costly energy, the sites of ULCOWIN (16) and biomass ULCORED with excess syngas (15) become economic only at the higher carbon trading price. The coal-based ULCORED with excess syngas (13) would also require the higher price despite it using a cheaper fuel because it incorporates a particularly low efficiency of gasification. Hence the coal ULCORED site without excess syngas (12) is preferable.

Figure 4-41 compares the abatement options under the future dynamic regime and 100£/tCO_2 price, but with the V4 configuration at the TGR-BF sites (5, 6), and the sale of captured CO_2 from HIsarna (8) and TGR-BF (5) for CCU with 67% avoidance rate. HIsarna has also switched in fuel to charcoal.

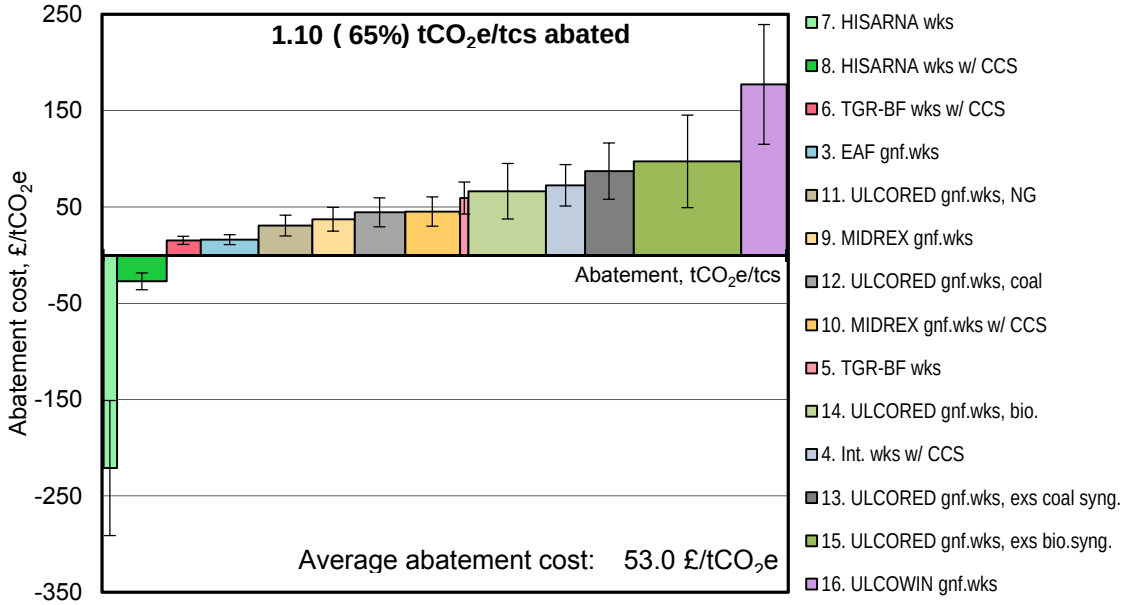

Figure 4-38: Comparative AC curve of abatement options in the UK iron and steel sector under the future dynamic (2030) regime

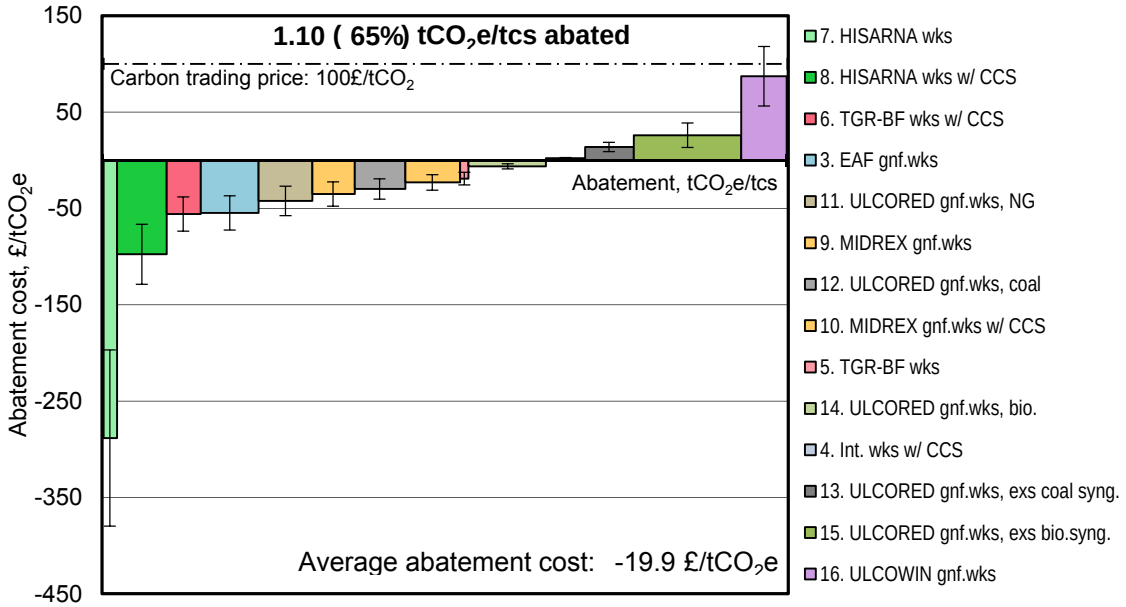

Figure 4-39 : Comparative AC curve of abatement options in the UK iron and steel sector under the future dynamic (2030) regime and a carbon trading price reaching 100£/tCO$_2$ in 2050

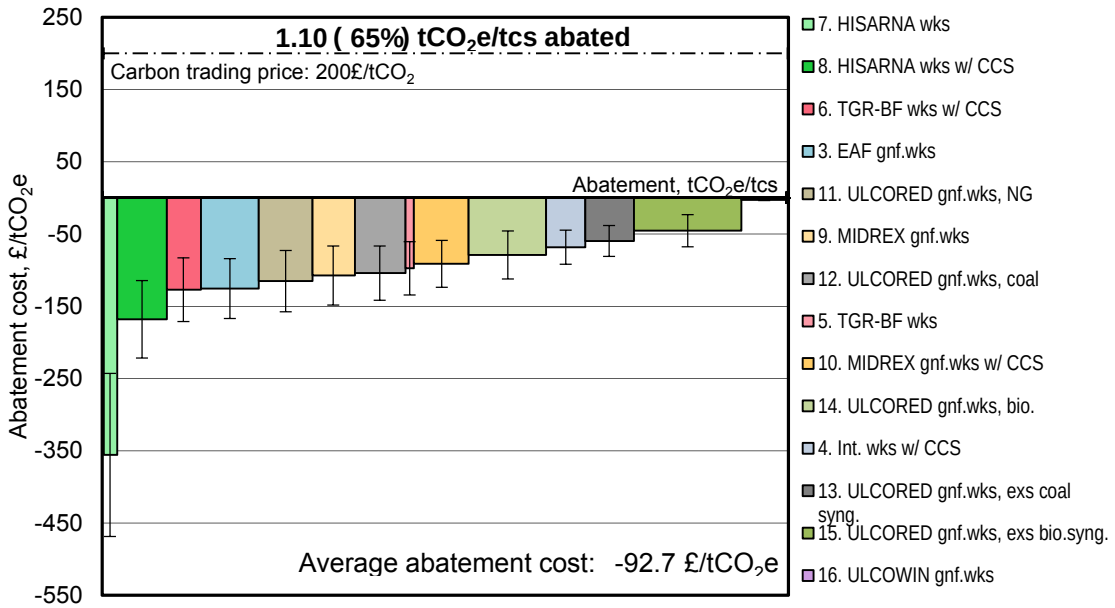

Figure 4-40 : Comparative AC curve of abatement options in the UK iron and steel sector under the future dynamic (2030) regime and a carbon trading price reaching 200£/tCO₂ in 2050

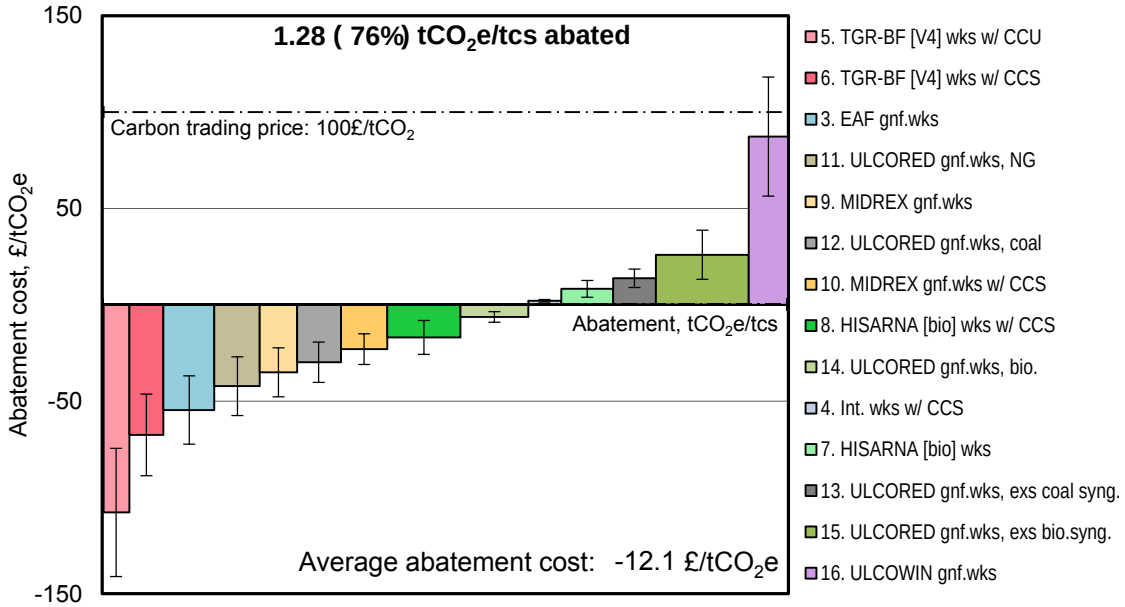

Figure 4-41 : Comparative AC curve of abatement options from 2030 in the UK iron and steel sector with equal production share, carbon fixation, and a carbon trading price reaching 100£/tCO₂ in 2050

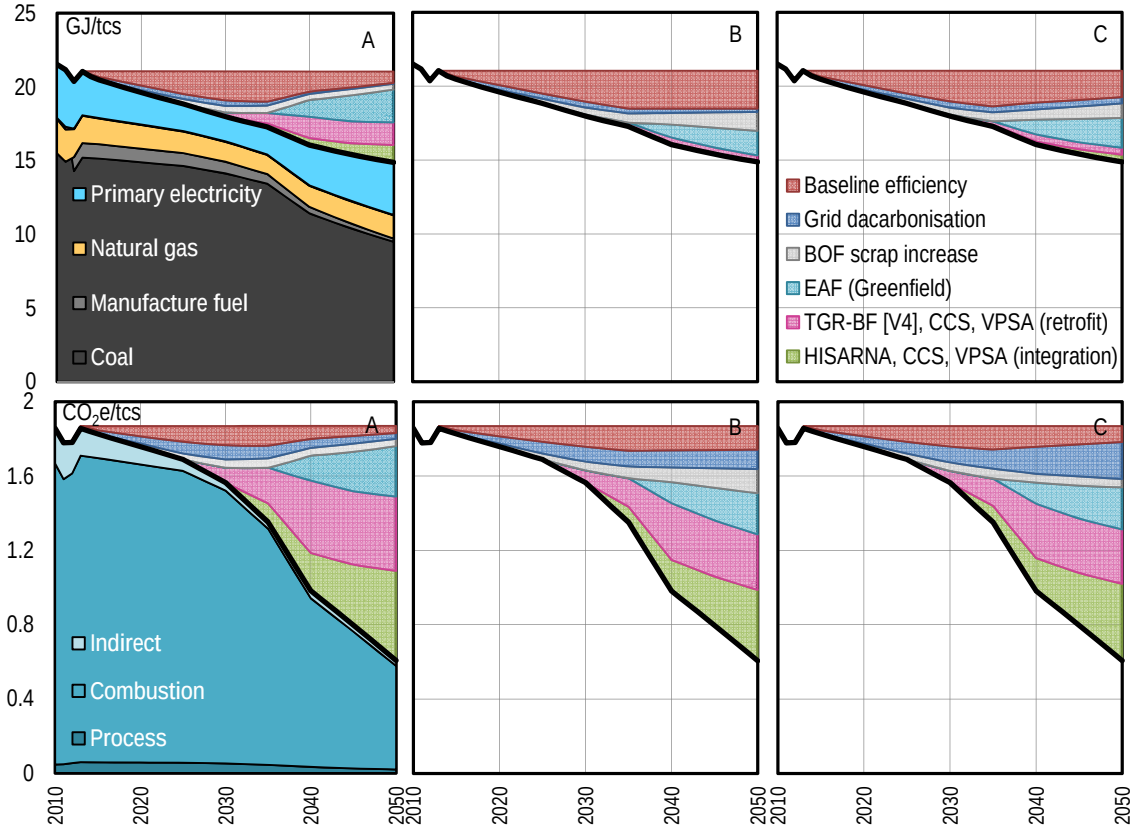

Figure 4-42: Multi-perspective decomposition of future energy and GhG emissions intensity for the reasonable action with CCS (RA-CCS) 2050 roadmap of the UK iron and steel sector

4.5.5 Roadmaps

This section introduces the concept of roadmap perspectives and exhibits numerous illustrative 2050 roadmaps. Key roadmaps are presented with a multi-perspective decomposition of projected sector energy and GhG emissions intensity reduction. The projected baseline is fixed between roadmaps so as to provide a consistent basis for comparing their conflictive and synergistic effects with the replacement technologies. For figures on the deployment of technologies and measures for each roadmap refer to section A5.6 of the Appendix.

4.5.5.1 Roadmap perspectives

Changes relating to baseline efficiency, BOF scrap and the grid may be described collectively as crosscutting measures insofar as their effects are not confined to a single site option. The effects do, however, vary between sites. Some equipment grouped into baseline efficiency may be installed at one site but not another, e.g. CDQ may be deployed at the integrated works but not at the EAF site, or *vice versa* with respect to scrap preheating. Furthermore, BOF scrap increase can only occur at sites with BOF capacity and the effect of grid decarbonisation is proportional to the amount of electricity a site purchases.

The measure of change from replacement technologies, or the sites representing them, is dependant on the attribution of crosscutting measures. This is depicted in Figure 4-42, which

gives three perspectives (A, B and C) on attributed energy and emissions intensity reduction for an illustrative roadmap: Reasonable action with CCS (RA-CCS). Resulting energy and emissions intensity after reduction are also shown to highlight the effect on fuel split and emissions by source.

In this roadmap, CCS equipped TGR-BF and HIsarna technologies are applied equally to two thirds of existing integrated site capacity in 2050. The remaining third is half replaced by Greenfield EAF capacity. Projected grid decarbonisation is met and sector scrap level reaches the mean (45%) of the projected range (supplying a 23% BOF scrap input and 30% EAF production). Baseline efficiency is defined as reaching two thirds of the BAT standard (which includes slag heat recovery and 33% thin slab casting) by 2030 where it remains.

The total change in energy or emissions (E) is the overall effect of crosscutting measures (C) and replacement technologies (R), and is given by equation (4-1). In this example there are three crosscutting measures (baseline efficiency, grid improvement, BOF scrap increase) and three replacement technologies (Greenfield EAF, TGR-BF with CCS, and HIsarna with CCS).

$$E = C + R \tag{4-1}$$

Perspective A shows the effect of crosscutting measures applied at sites that are incumbent in 2010. The effect reduces as the incumbents are transformed or displaced by the deployment of replacement technologies. Where crosscutting measures occur with the replacement technologies, their effect is attributed to them. Equation (4-2) expresses how perspective A is calculated from energy, or emissions, pathways (P) generated by the roadmap projection model. P_0 is the base pathway[26] and excludes all crosscutting and replacement measures. P_c is the pathway arising from the uptake of crosscutting measures only. P_{ic} is the pathway arising from the deployment of replacement technology i and crosscutting measures. x_i is the proportion of sector production occurring via replacement technology i, and x_b is the proportion of sector production that does not occur via replacement technologies.

$$E_A = C_A + R_A = x_b(P_c - P_0) + \sum_{i=0}^{n} R_i \tag{4-2}$$

where:

$$R_i = (P_{ic} - P_0) - (1 - x_i)(P_c - P_0) \tag{4-3}$$

Perspective B shows the effect of applying replacement technologies to the sector otherwise improved by crosscutting measures only. The crosscutting effects shown are as they would be in

[26] By definition this has constant intensity, however it may change in absolute terms with sector production level.

the absence of any replacement technology deployment. Thus the replacement technology effects shown are the true effects of their deployment when viewed as the alternative to no deployment. As can be observed, the effects of EAF, TGR-BF and HIsarna are less than from perspective A. The effect is expressed by equation (4-4) where P_r and P_{rc} are the pathways arising from the application of all replacement technologies in the absence and the presence of crosscutting measures respectfully. The calculation of individual crosscutting measures is expressed by equation (4-5). Subscript j denotes the presence of a specific crosscutting measure while subscript $\bar{j}$ denotes the absence of a specific crosscutting measure and the presence of all other crosscutting measures.

$$E_B = C_B + R_B = (P_r - P_0) + (P_{rc} - P_r) \quad (4\text{-}4)$$

and:

$$C_B = \sum_{j=0}^{n} C_j = \frac{1}{2}\left[(P_c - P_{\bar{j}}) + (P_j - P_0)\right] \quad (4\text{-}5)$$

In contradistinction to perspective B, perspective C shows the effect of applying crosscutting measures to the sector otherwise improved by replacement technologies only. As can be observed, the effect of grid decarbonisation increases. This is because the sector structure demands an increasing amount of purchased electricity as it transforms. Conversely, the effect of BOF scrap is lowered as there becomes less BOF capacity to replace and processes upstream of the BOF have significantly reduced energy and emissions intensity. HIsarna has a greater conflict with baseline efficiency because it replaces more of these upstream processes than would TGR-BF; the former replaces coke oven capacity and sinter plant while the latter only partly replaces coke oven capacity and maintains sinter plant. This is evidenced by a greater increase in HIsarna's impact from perspective B to perspective C. The effect is expressed by equation (4-6). The calculation of individual crosscutting measures is expressed by equation (4-5).

$$E_C = C_C + R_C = (P_{rc} - P_c) + (P_c - P_0) \quad (4\text{-}6)$$

and:

$$C_C = \sum_{j=0}^{n} C_j = \frac{1}{2}\left[(P_{rc} - P_{r\bar{j}}) + (P_{rj} - P_r)\right] \quad (4\text{-}7)$$

4.5.5.2 Reasonable action roadmap

The 'Reasonable action' (RA) roadmap represents a future in which new process technologies are deployed but without drastic transitional changes to sector structure or dependence on CCS. This roadmap is as RA-CCS but without CCS.

4.5.5.3 Reasonable action with CCS roadmap

The 'Reasonable action with CCS' (RA-CCS) roadmap is described in section 4.5.5.1. Perspectives on attributed energy and emissions intensity reduction are shown in Figure 4-42. A biomass counterpart roadmap, RA-CCS [bio], incorporates the charcoal-based HIsarna instead of the coal-based HIsarna. Perspectives are shown in Figure 4-43 where the dashed line is the emissions profile for which carbon fixation is unaccounted.

Note that BOF scrap increase ultimately reduces abatement in Figure 4-43 because it is displacing the process of extracting emissions from the atmosphere through the combination of carbon fixation and storage. However, the grid decarbonisation effect is marginally higher than in Figure 4-42 because charcoal-based HIsarna is modelled with slightly lower efficiency resulting in a higher CO_2 intensity and so a larger electricity purchase relating to VPSA separation.

4.5.5.4 Gas process transition roadmap

The 'Gas process transition' (GT) roadmap represents a future in which two thirds of blast furnace capacity is replaced by natural gas based DRI. Specifically, investment is made in Greenfield MIDREX capacity coupled with EAF. Sector scrap share rises to the mean of the projected range (45%). Perspectives on attributed energy and emissions intensity reduction are shown in Figure 4-44.

4.5.5.5 Gas process transition with CCS roadmap

The 'Gas process transition with CCS' (GT-CCS) roadmap is similar to GT but with natural gas based ULCORED (with CCS) as the choice of technology in place of the MIDREX system. Perspectives on attributed energy and emissions intensity reduction are shown in Figure 4-45. As ULCORED is a less mature technology than MIDREX, it follows a shallower deployment profile over the medium-term before reaching the same deployment level in 2050.

4.5.5.6 Radical process transition roadmap

The 'Radical process transition' (RT) roadmap represents an ambitious structural shift culminating in the ultimate cessation of blast furnace ironmaking in the UK. There is also no dependence on CCS. Perspectives on attributed energy and emissions intensity reduction are shown in Figure 4-46. All steel conversion takes place in EAFs with an average 45% iron input for the sector, i.e. having the upper boundary (55%) of projected sector scrap share. The iron is supplied five eighths from MIDREX and three eighths from ULCOWIN, equating to a 70/30 share in 2050 production from these sites respectively. Note that ULCOWIN demands more energy and virtually all of its abatement relies on grid decarbonisation. BAT improvement measures reduce more significantly in graph C as more capacity is replaced by Greenfield sites.

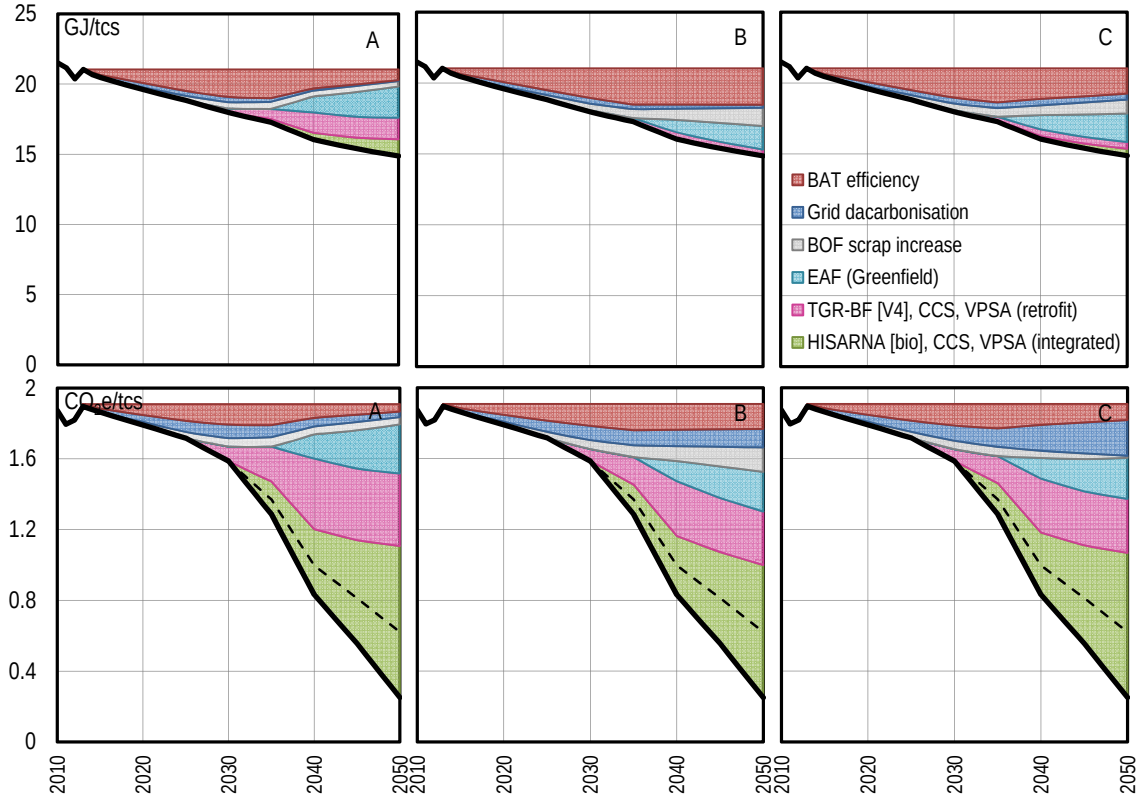

Figure 4-43: Multi-perspective decomposition of future energy and GhG emissions intensity for the reasonable action with biomass CCS (RA-CCS [bio]) 2050 roadmap of the UK iron and steel sector

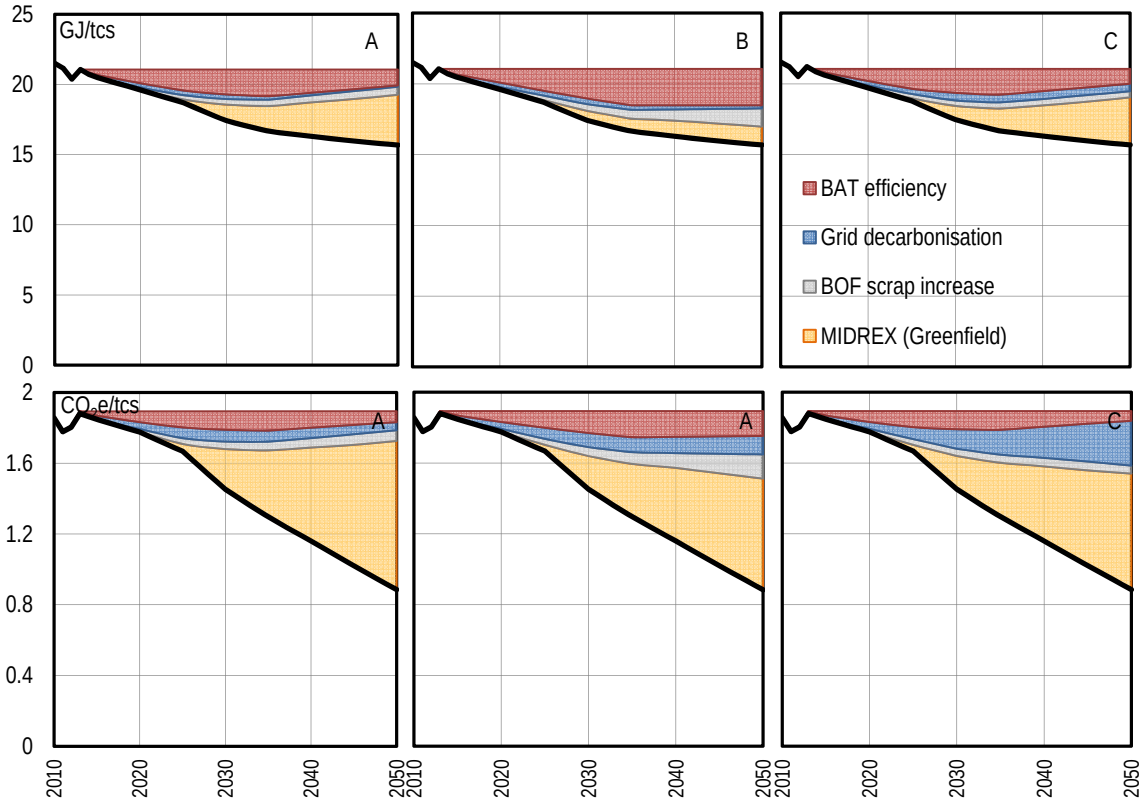

Figure 4-44: Multi-perspective decomposition of future energy and GhG emissions intensity for the gas process transition (GT) 2050 roadmap of the UK iron and steel sector

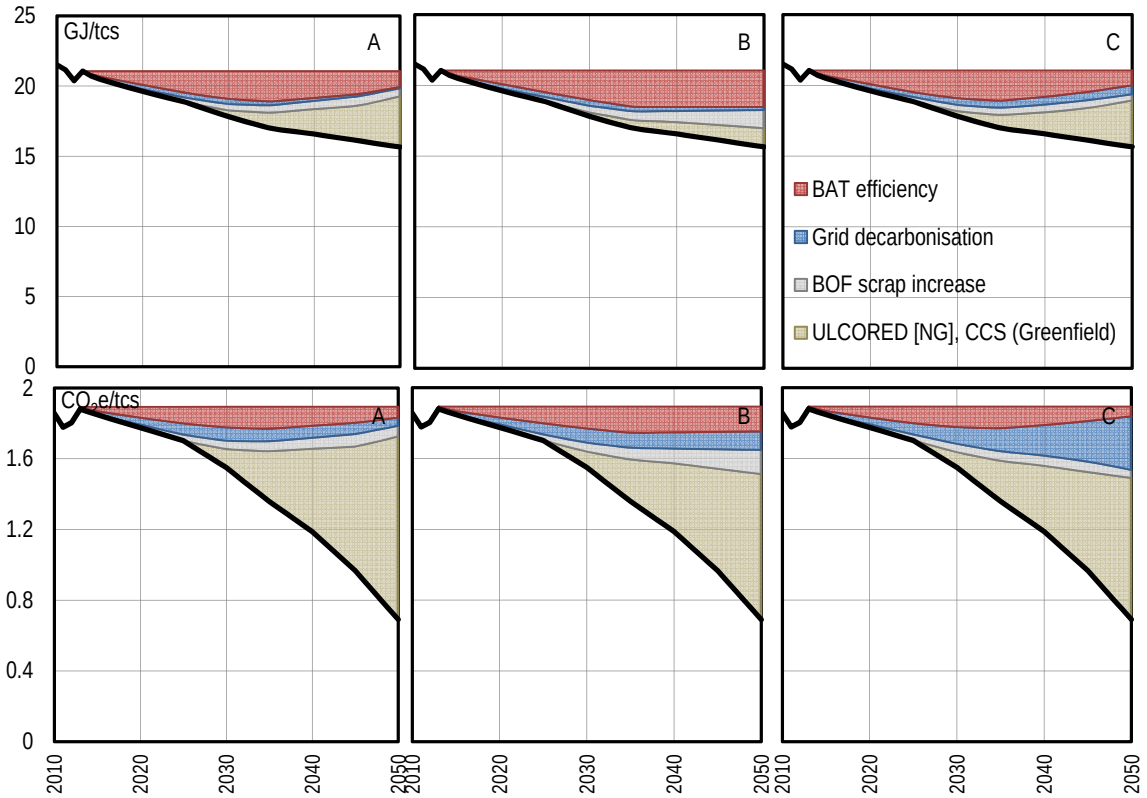

Figure 4-45: Multi-perspective decomposition of future energy and GhG emissions intensity for the gas process transition with CCS (GT-CCS) 2050 roadmap of the UK iron and steel sector

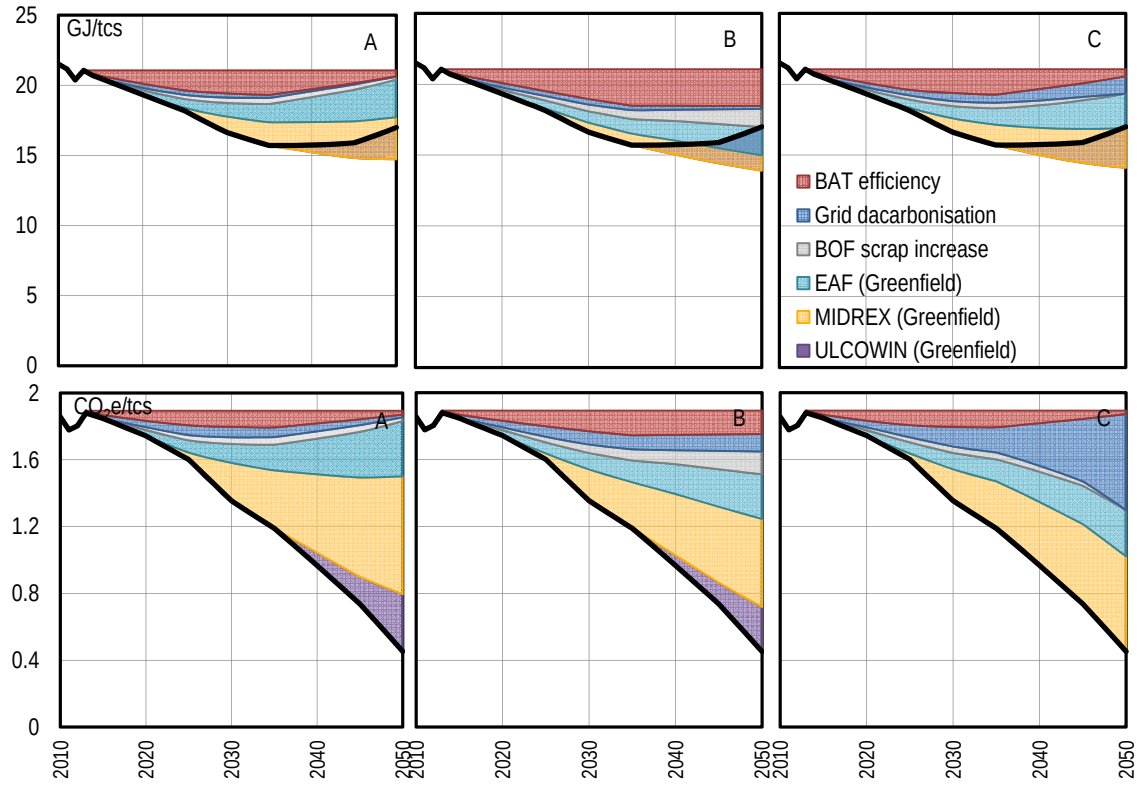

Figure 4-46: Multi-perspective decomposition of future energy and GhG emissions intensity for the radical process transition (RT) 2050 roadmap of the UK iron and steel sector

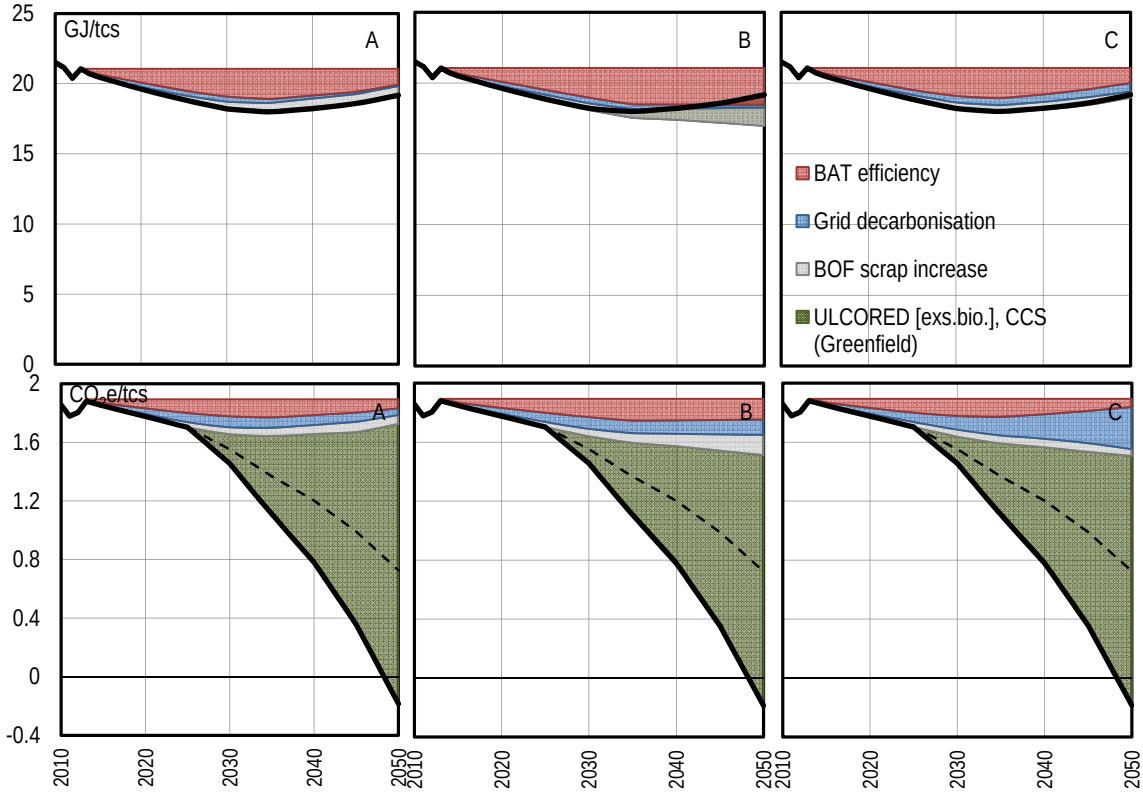

Figure 4-47: Multi-perspective decomposition of future energy and GhG emissions intensity for the biomass process transition with CCS (BT-CCS) 2050 roadmap of the UK iron and steel sector

4.5.5.7 Existing process transition roadmap

The 'Existing process transition' (ET) roadmap is so-called as it represents a structural transition of existing UK processing methods only. Recycling is increased such that the maximum sector projection for scrap (55% share) is reached in 2050. With BOF scrap input at 23% of metallic charge, BOF/EAF share of crude steel production becomes 57/43.

4.5.5.8 Biomass process transition with CCS roadmap

The 'biomass process transition with CCS' (BT-CCS) roadmap is identical to GT-CCS except ULCORED technology is coupled with a biomass gasification unit. Also modelled is the roadmap BT2-CCS, in which gasification is scaled up and excess syngas put to use in other processes, including electricity generation. Perspectives on attributed energy and emissions intensity reduction of the BT2-CCS roadmap are shown in Figure 4-47. The dashed line is the emissions profile for which carbon fixation is unaccounted.

4.5.6 Roadmap summary

Figure 4-48 shows sector GhG emission pathways of the assessed roadmaps and the projected baseline. Graph A includes direct emissions (scope 1) and graph B includes direct and indirect emissions (scope 1-2/3), which encompasses electricity generation and delivery. Also shown are the trajectories of three relevant decarbonisation targets. Supplementary model outputs may be referred to in section A5.6.1 of the Appendix.

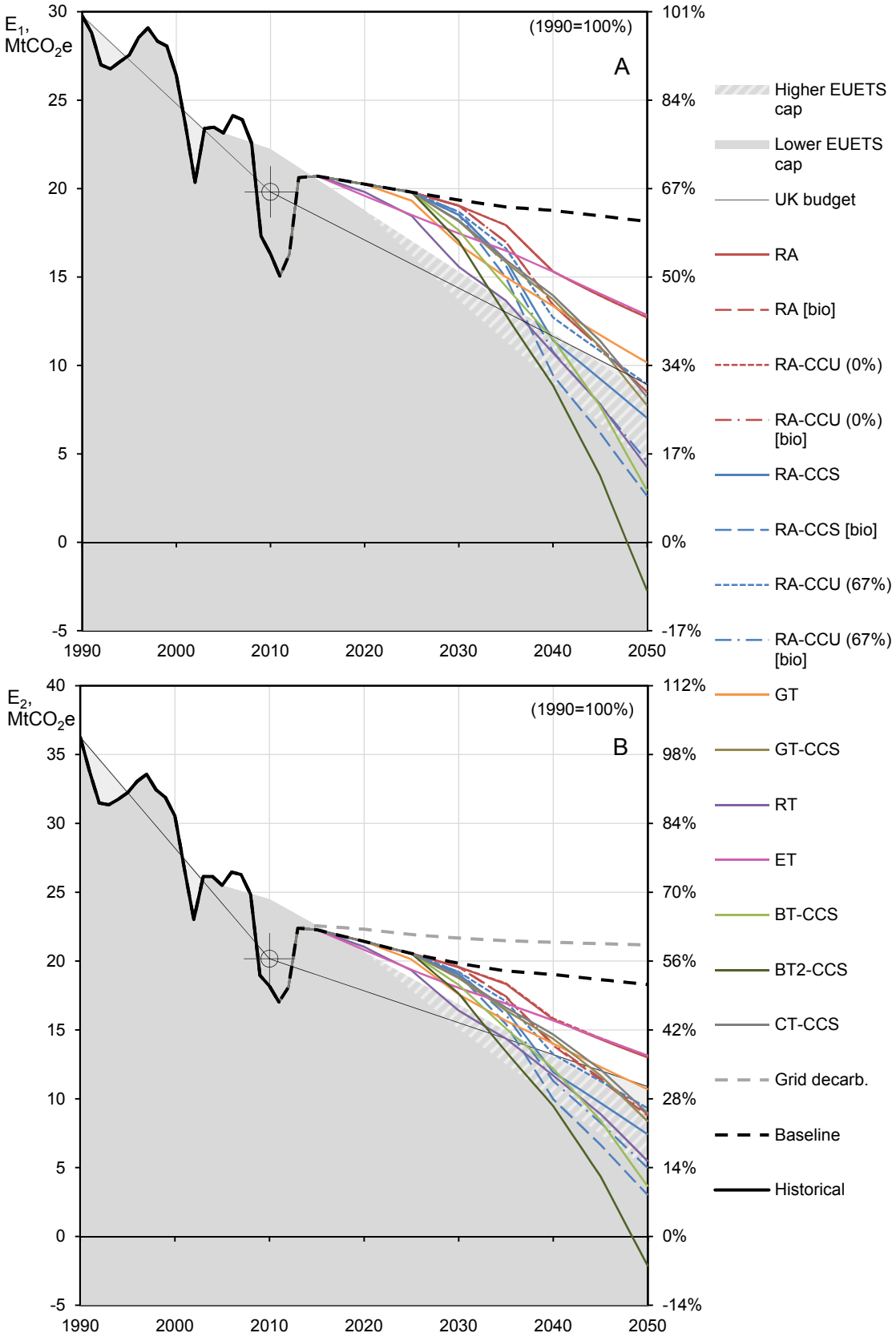

Figure 4-48: GhG emissions pathways of illustrative technology roadmaps for the UK iron and steel sector

The first target is a 70%[27] GhG emissions reduction from 1990 levels. This is the reduction indicated for the industrial sector in the UK Carbon Plan (HM Government 2011) for contributing to the legislated commitment of 80% at the national level (HM Government 2008). The second trajectory follows the mandatory 1.74% annual reduction cap of EUETS phase III (European Commission 2009b), which begins from a 2010 base and has been agreed to reduce continuously along the same path beyond 2020 (European Commission 2011). The EUETS began in 2005 and emissions reduction amounts to 21% in 2020 from 2005 levels, extrapolating to about 70% in 2050. The third trajectory is the mean of a long-term reduction path suggested for EUETS sectors of 43-48% in 2030 and 88-92% in 2050 compared with 2005 levels (ibid.).

The two European targets are referred to hereon as the higher and lower EUETS caps respectively; the domestic goal is referred to as the UK budget. It is noted that the EUETS caps apply to direct CO_2 emissions from specified installations amounting to 90% of GhG emissions in the sector in 2010 (see section 4.2.3.1). The domestic goal covers total sector GhG emissions. Though the EUETS only applies to scope 1 emissions, the limits presented in graph A and graph B are proportionally the same.

Figure 4-49 compares dynamic sector production costs for the roadmaps relative to the projected baseline under increasing steps of emissions trading price. For simplicity, the trading price is incorporated in each case as rising linearly from 0£/tCO_2 in 2010. The sector would profit in the absence of emissions trading from some of the RA roadmaps. Over the middle steps of trading price, RA roadmaps generally have the most attractive economics. With the price increasing to 200£/tCO_2 in 2050, RA roadmaps without CCUS fade in their appeal relative to RT and BT roadmaps, and RA-CCS [bio] becomes more economically attractive than RA-CCS.

Figure 4-49 shows that considerable savings in future production cost may be available from the technology roadmaps. However, these savings exist in the context of absolute increases in production cost, which should not be allowed to become uncompetitive. Figure 4-50 shows the absolute cost of production for the roadmaps and the baseline over the same emissions trading price steps. Regardless of trading price, production cost will increase alongside resource costs with the baseline rising to about 550£/tcs in 2050. At a trading price of 50£/tCO_2 in 2050, the sector can only avoid a discernible increase on this production cost by pursuing the RA-CCU (67%) roadmap, i.e. by switching two thirds of existing primary steel production to TGR-BF and HIsarna technology and selling captured carbon at 50£/tCO_2 to CCU applications with a two thirds avoidance rate. Beyond the 50£/tCO_2 trading price, however, no roadmap avoids an increase on the 0£/tCO_2 baseline production cost. This highlights the need for policy measures that support as well as penalise the industry.

[27] See section A1 of the Appendix for the translation of this emissions target into an emissions trajectory.

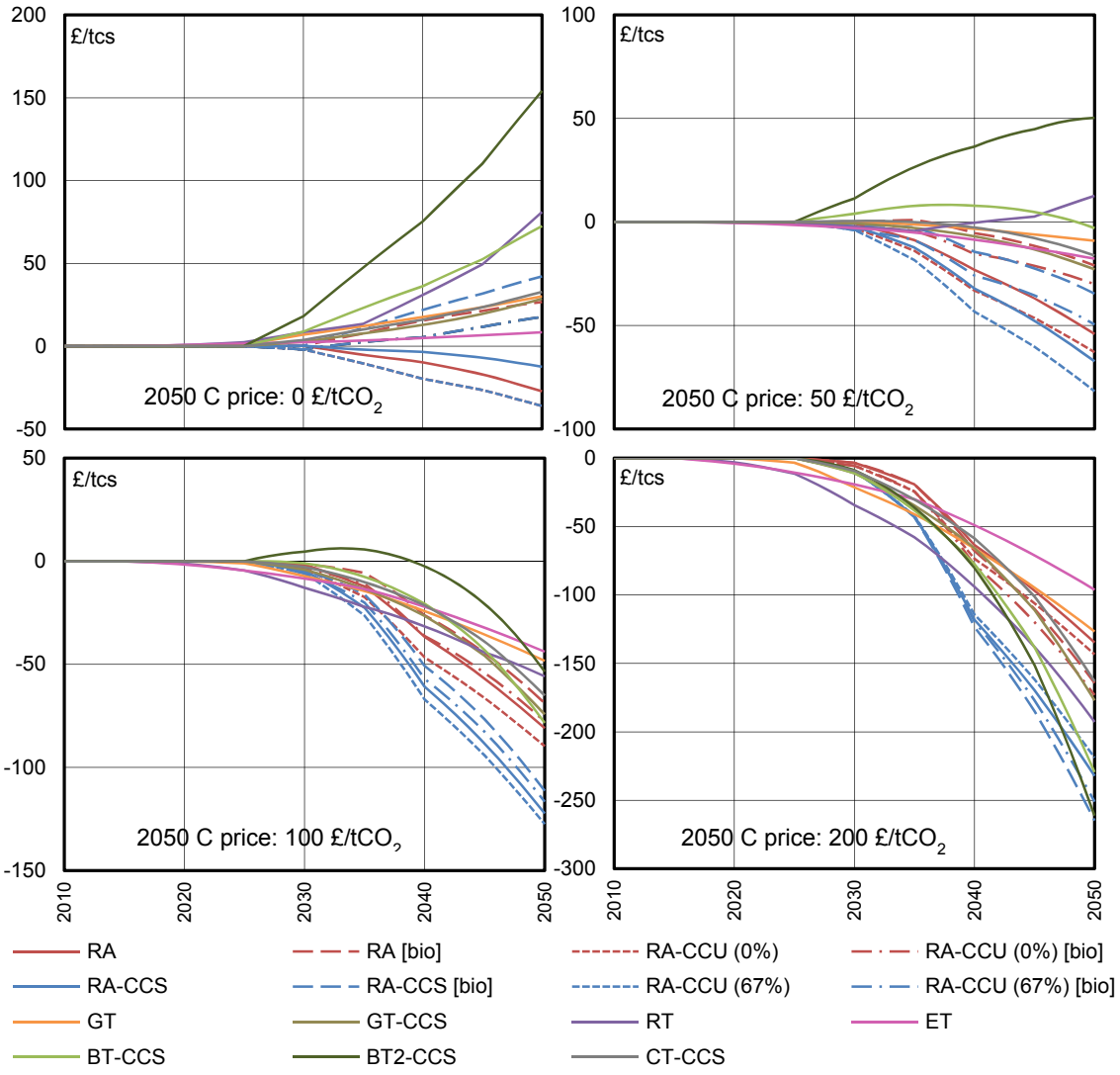

Figure 4-49: Relative production cost pathways of illustrative technology roadmaps of the UK iron and steel sector

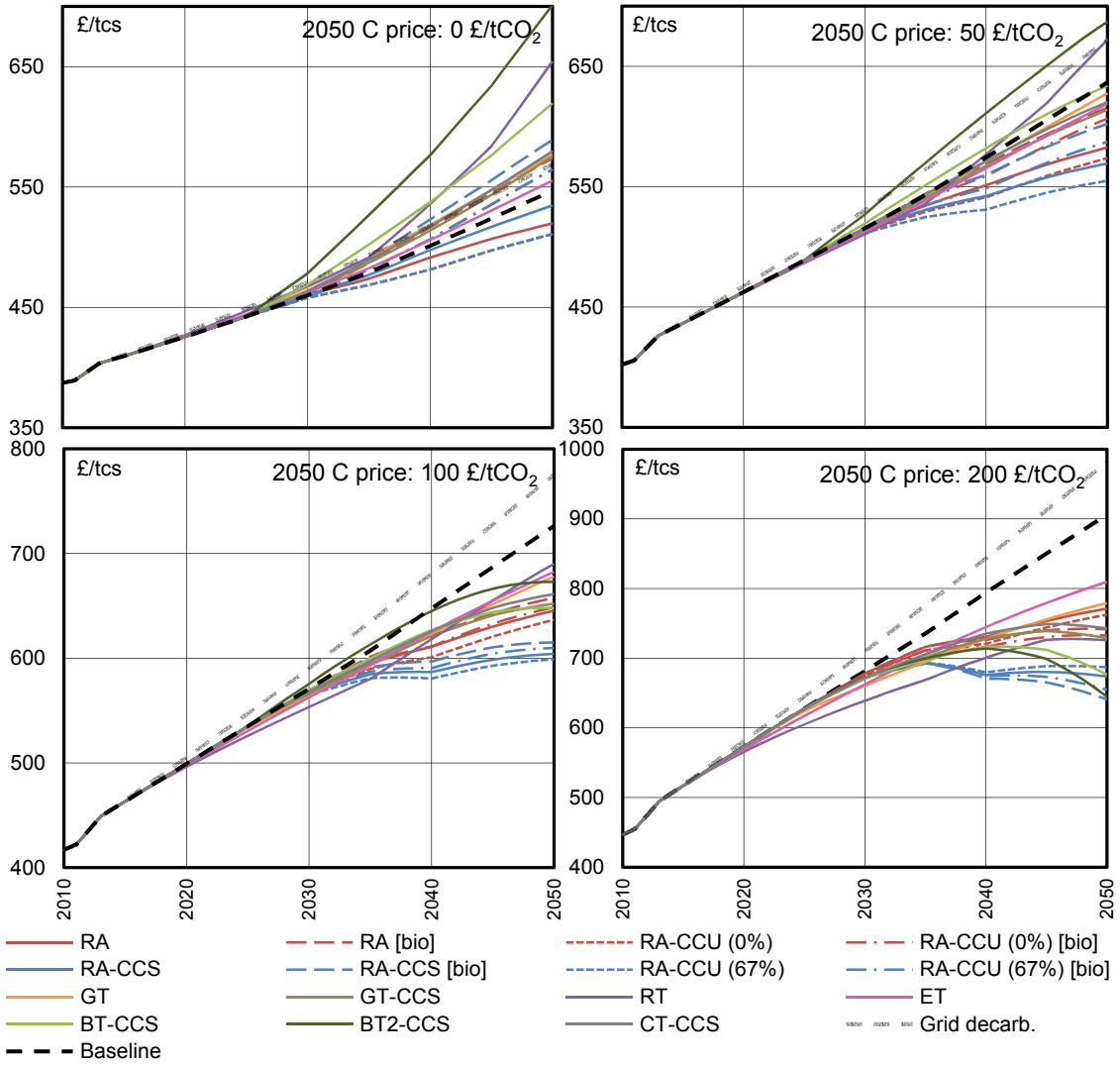

Figure 4-50: Production cost pathways of illustrative technology roadmaps of the UK iron and steel sector

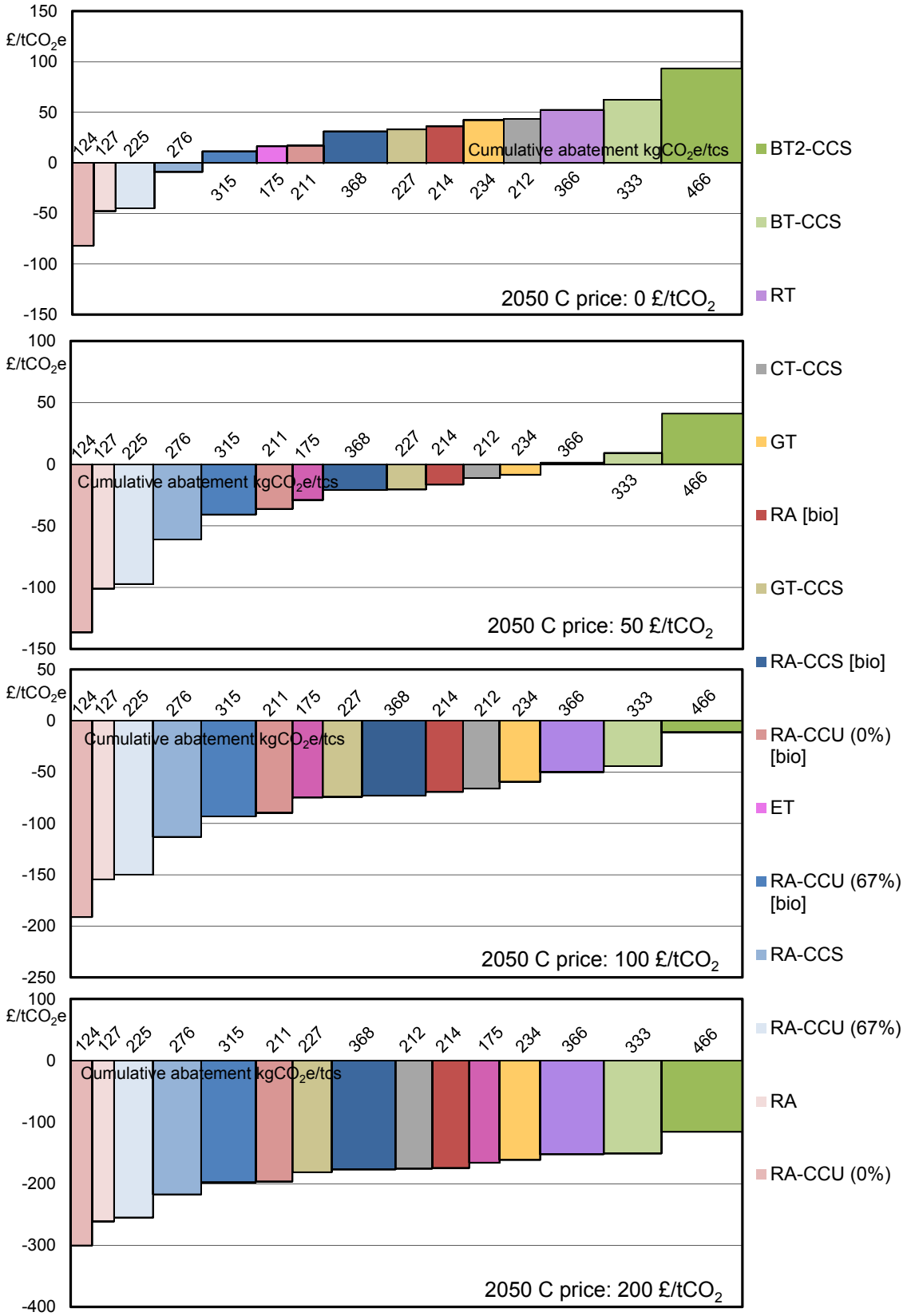

Figure 4-51: Comparative AC curves of illustrative technology roadmaps of the UK iron and steel sector for increasing steps of emissions trading price

In order to rank the roadmaps it is useful to account for cumulative cost and abatement (direct and indirect emissions). Over the years 2011-2050 the projected baseline will emit 794MtCO_2 for a production of 475Mtcs, equating to an average emissions intensity of 1.67tCO_2e/tcs. Average production cost over the period without emissions trading is 467£/tcs: a 20% increase on the cost in 2010 of 387£/tcs. Figure 4-51 is a comparative AC curve of the roadmaps by average annual abatement and abatement cost. Accounting for total emissions over the period favours roadmaps that impact sooner. For example, the RT roadmap abates a similar emission to the RA-CCS [bio] roadmap, though it leads to a reasonably higher emitting sector in 2050.

Larger abatements could be achieved by adjusting crosscutting measures. For the RA-CCS [bio] roadmap, it was shown that increasing BOF scrap rate can actually reduce abatement. Further to this, lower BOF scrap rate would leave more room for CCS and EAF production. RA2 was constructed in which the initial BOF scrap rate of 15% is maintained. The same sector scrap rate in RA is then achieved by transferring more scrap to EAF production. RA2-CCS and RA2-CCS [bio] have average annual abatements 292kgCO_2e/tcs and 390kgCO_2e/tcs respectively. Yet further abatement would be achieved under a more aggressive grid decarbonisation pathway. RT would have an average annual abatement of 412kgCO_2e/tcs, while RA-CCS [bio] and RA2-CCS [bio] would abate 392kgCO_2e/tcs and 415kgCO_2e/tcs respectively.

The limit on direct emissions imposed by the EUETS caps is 539-605MtCO_2e, requiring an average annual abatement of 341-480kgCO_2e/tcs (454-506kgCO_2e/tcs for the lower cap range). Only BT2-CCS, which abates 480kgCO_2e/tcs, falls within the lower cap's compliance range.

4.5.6.1 The wider perspective

Under the Monitoring and Reporting Regulation (MRR) of the EUETS and official UK reporting guidelines, biomass is a carbon neutral fuel (AEA 2012, European Commission 2012d). In reality, biomass can be carbon neutral only if it is additional to that which would otherwise have grown and decomposed, i.e. counterfactual (Haberl et al. 2012). And even replacing harvested stocks can lead to a 'pulse' of climatic forcing associated with a lag in the effective reabsorption of combusted emissions (ibid.). Figure 4-52 maps average cost and cumulative direct emissions abatement of the roadmaps with reference to the abatement required in complying with the EUETS caps and UK budget. The filled data points are roadmaps that use biomass and are shown with the difference attributable to carbon fixation. The emissions trading price is treated here as sensitive to the inclusion of carbon fixation, hence production cost reduces under an emissions trading price. The effect of the range of potential emissions factors for biomass is represented by the gradient coloured lines. At about a third the maximum emission factor for biomass, RT becomes the only roadmap to comply with the higher EUETS cap.

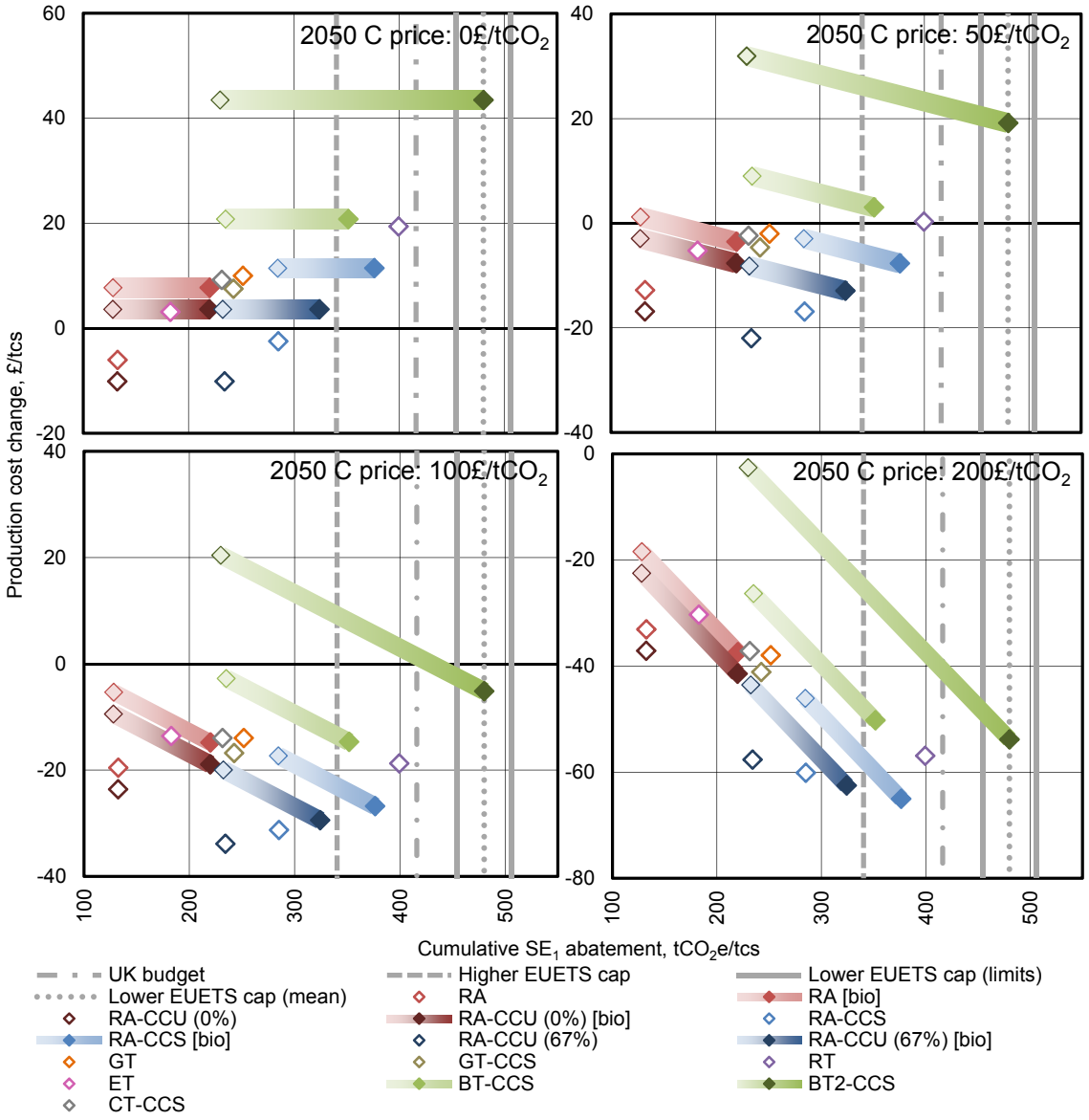

Figure 4-52: Average production cost change and cumulative SE_1 abatement of illustrative technology roadmaps of the UK iron and steel sector for increasing steps of emissions trading price

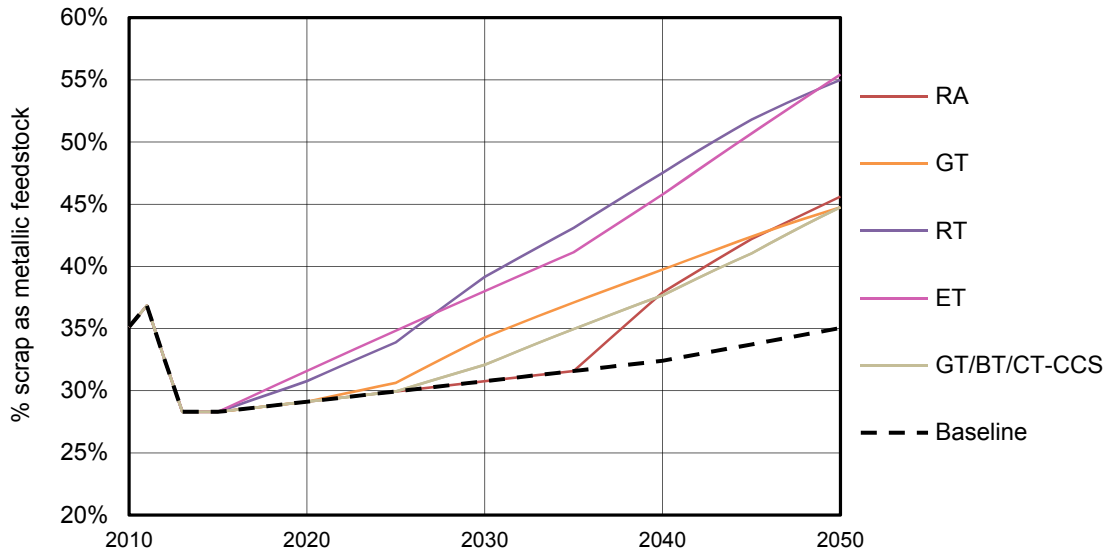

Figure 4-53: Scrap share of metallic feedstock for illustrative roadmaps of the UK iron and steel sector

As with biomass supply, the question of where the scrap supply derives and at what indirect environmental cost should be considered before attributing emissions reduction. Figure 4-53 shows specific scrap consumption trajectories of the roadmaps. As previously discussed, the projected increases in scrap consumption in the UK are informed by future increases in construction scrap arising, first at the European level and then the global level, and which is in addition to the large European stockpile. If scrap consumption in the UK iron and steel sector increased in-line with increases worldwide, then the associated reduction in domestic emissions would translate to an equal reduction in global emissions. But if UK scrap consumption is increased by diverting exports that supply scrap-based production outside of the UK, this could result in a zero net displacement of primary steel production with no effect on global emissions.

4.5.6.2 Optimised roadmaps

So far future pathways for the sector have been assessed with illustrative roadmaps that broadly cover the range of identified technology options. A group of roadmaps optimised for meeting emissions targets while minimising costs or avoiding progress bottlenecks is assessed here. Given the high costs associated with biomass gasification, BT-CCS has been excluded. Instead focus is given to balancing the sector between radical process transition and approaches to CCUS at existing integrated sites.

Table 4-12 introduces and details a set of optimised roadmaps for the years 2011-2050 with abatement and abatement economics shown alongside other pertinent indicators. The roadmaps are listed in order of SE_2 abatement. Since actual abatement attributable to scrap and biomass increase is conditional, their use is shown and contributes to the stated risk to abatement reduction. Sector access to CCS enabling transport and storage technology is also uncertain, so reliance is stated alongside the designated risk associated with scrap and charcoal use. Visual representation of production cost and cumulative abatement is provided by Figure 4-54 and sector scrap share trends are displayed in Figure 4-55.

Within the subgroup of RA2-CCS, the lower EUETS cap is met with varying balances of scrap and charcoal. In RA3-CCS, HIsarna has a greater share of primary production allowing for greater amounts of charcoal and thus reducing the required rate of transition to secondary production. In RA4-CCS, all primary production (two thirds of total production) in 2050 is met by HIsarna enabling sufficient abatements depending on the fuel blend. In this case, the range of the lower emissions cap is achieved over a 75-100% charcoal-coal mix. In RA4.1-CCS the same uptake of HIsarna achieves the minimum of the target range with 100% charcoal but with only a marginal increase in scrap purchase (38Mt above static base) and requiring only a 10% switch in production to EAF in 2050 with a 15% BOF scrap share. However, by consuming 79Mt of charcoal the roadmap is heavily dependent on biomass, all of which must be sustainably sourced.

Roadmap ID	Description	Target met	Additional* purchased scrap consumption, Mt	Charcoal, Mt (EJ)	Average HIsarna blend (% charcoal)	CCUS Ab., $MtCO_2e$	Scope 1 GhG		Scope 1-2/3 GhG		2050 emissions trading price: 0£/tCO_2		2050 emissions trading price: 100£/tCO_2		Risk from counter-abatement resource externality	Reliant on CCS transport and storage?
							E_1, $MtCO_2e$	Ab. SE_1, $tCO2e/tcs$	E_2, $MtCO_2e$	Ab. SE_3, $tCO2e/tcs$	Average prod. cost, £/tcs	Average ab. cost, £/tCO_2e	Average prod. cost, £/tcs	Ab. Cost, £/tCO_2e		
Baseline	Scrap increase is lower limit of projected baseline; 23% BOF scrap share of charge; BOF/EAF 2050 crude steel prod as in 2013 = 84/16.	-	30.40	-	-	-	767	-	795	-	466	-	578	-	None	No
RA4-CCS [bio]	Accelarated scrap consumption from 2030; 2050 crude steel prod. 64% HIsarna CCS, 36% EAF	Lower EUETS cap (max)	64.29	78.8 (2.23)	100%	172	527	505	560	496	494	55.40	553	-50.12	High	Yes
RA4-CCU (67%) [bio]	Accelarated scrap consumption from 2020; 2050 primary crude steel prod. 64% HIsarna CCU (67% abatement), 36% EAF	Lower EUETS cap (mean)	80.13	78.8 (2.23)	100%	115	540	478	573	468	486	41.25	549	-62.93	High	No
RET	Drastically accelarated scrap consumption; 2050 crude steel prod. 100% EAF	Lower EUETS cap (mean)	274	-	-	-	540	479	577	460	475	17.86	541	-80.04	Very high	No
RA4.1-CCS [bio]	Accelarated scrap consumption from 2030; 2050 crude steel prod. 64% HIsarna CCS, 10% BF, 26% EAF	Lower EUETS cap (min)	38.04	78.8 (2.23)	100%	172	552	453	583	446	493	59.94	558	-45.46	Medium	Yes
RA4.1-CCU (67%) [bio]	Accelarated scrap consumption from 2025; 2050 crude steel prod. 64% HIsarna CCU (67%), 36% EAF	Lower EUETS cap (min)	67.12	78.8 (2.23)	100%	115	552	453	585	444	485	42.67	550	-62.77	Medium	No
RA3-CCS [bio]	Accelarated scrap consumption from 2025; 2050 crude steel prod. 42% HIsarna CCS, 14% TGR-BF, 8% BF, 36% EAF.	Lower EUETS cap (min)	65.18	54.85 (1.55)	95%	170	552	453	585	443	486	44.81	552	-59.48	Medium	Yes
RA3-CCU (67%) [bio]	Greatly accelarated scrap consumption from 2020; 2050 crude steel prod. 42% HIsarna CCU (67%), 14% TGR-BF CCU (67%), 8% BF, 36% EAF.	Lower EUETS cap (min)	82.42	57.74 (1.63)	100%	114	552	453	586	441	482	34.50	548	-68.53	High	No
RA2.1-CCS [bio]	Accelarated scrap consumption from 2020; 2050 crude steel prod. 28% HIsarna CCS, 28% TGR-BF CCS, 8% BF, 36% EAF.	Lower EUETS cap (min)	84.75	36.46 (1.03)	100%	168	552	453	586	440	481	34.19	549	-67.40	Medium	Yes
RA2.2-CCS [bio]	Accelarated scrap consumption from 2015; 2050 crude steel prod. 28% HIsarna CCS, 28% TGR-BF CCS, 8% BF, 36% EAF.	Lower EUETS cap (min)	92.17	30.99 (0.88)	85%	167	552	453	587	439	479	29.63	547	-71.04	Medium	Yes
RA2.3-CCS [bio]	Accelarated scrap consumption from 2015; 2050 crude steel prod. 28% HIsarna CCS, 28% TGR-BF CCS, 8% BF, 36% EAF.	Lower EUETS cap (min)	97.16	27.34 (0.77)	75%	167	552	453	587	439	478	26.58	546	-73.69	Medium	Yes
RA2.1-CCU (67%) [bio]	Accelarated scrap consumption from 2015; 2050 crude steel prod. 28% HIsarna CCU (67%), 28% TGR-BF CCU (67%), 8% BF, 36% EAF	Lower EUETS cap (min)	98.12	36.46 (1.03)	100%	112	552	453	587	439	478	26.10	546	-73.99	High	No
RT2	Greatly accelarated scrap consumption; 2050 crude steel prod. 33% MIDREX, 33% ULCOWIN, 33% EAF mill	Lower EUETS cap (min)	157	-	-	-	552	453	600	412	490	57.04	560	-43.77	High	No
RT3	Greatly accelarated scrap consumption; 2050 crude steel prod. 10% MIDREX, 50% ULCOWIN, 40% EAF mill	Lower EUETS cap (min)	158	-	-	-	552	454	602	406	494	67.42	564	-35.66	High	No
RA4 [bio]	Accelarated scrap consumption from 2025; 2050 crude steel prod. 64% HIsarna, 36% EAF	Higher EUETS cap	67.63	78.8 (2.23)	100%	-	606	339	635	337	485	56.63	562	-46.97	High	No
RA2.4-CCS	Accelarated scrap consumption from 2020; 2050 crude steel prod. 28% HIsarna CCS, 28% TGR-BF CCS; 8% BF; 36% EAF	Higher EUETS cap	76.72	-	-	164	606	339	640	327	466	-0.45	545	-102.52	Medium-low	Yes

Table 4-12: Abatements, economics and other indicators for optimised technological roadmaps of the UK iron and steel sector, years 2011-2050 (474.8Mtcs produced)

*Purchased scrap is additional to 209Mt purchased and 105Mt home scrap consumed for the base sector which has a 15% BOF scrap share and a BOF/EAF share of 84/16 from 2013.

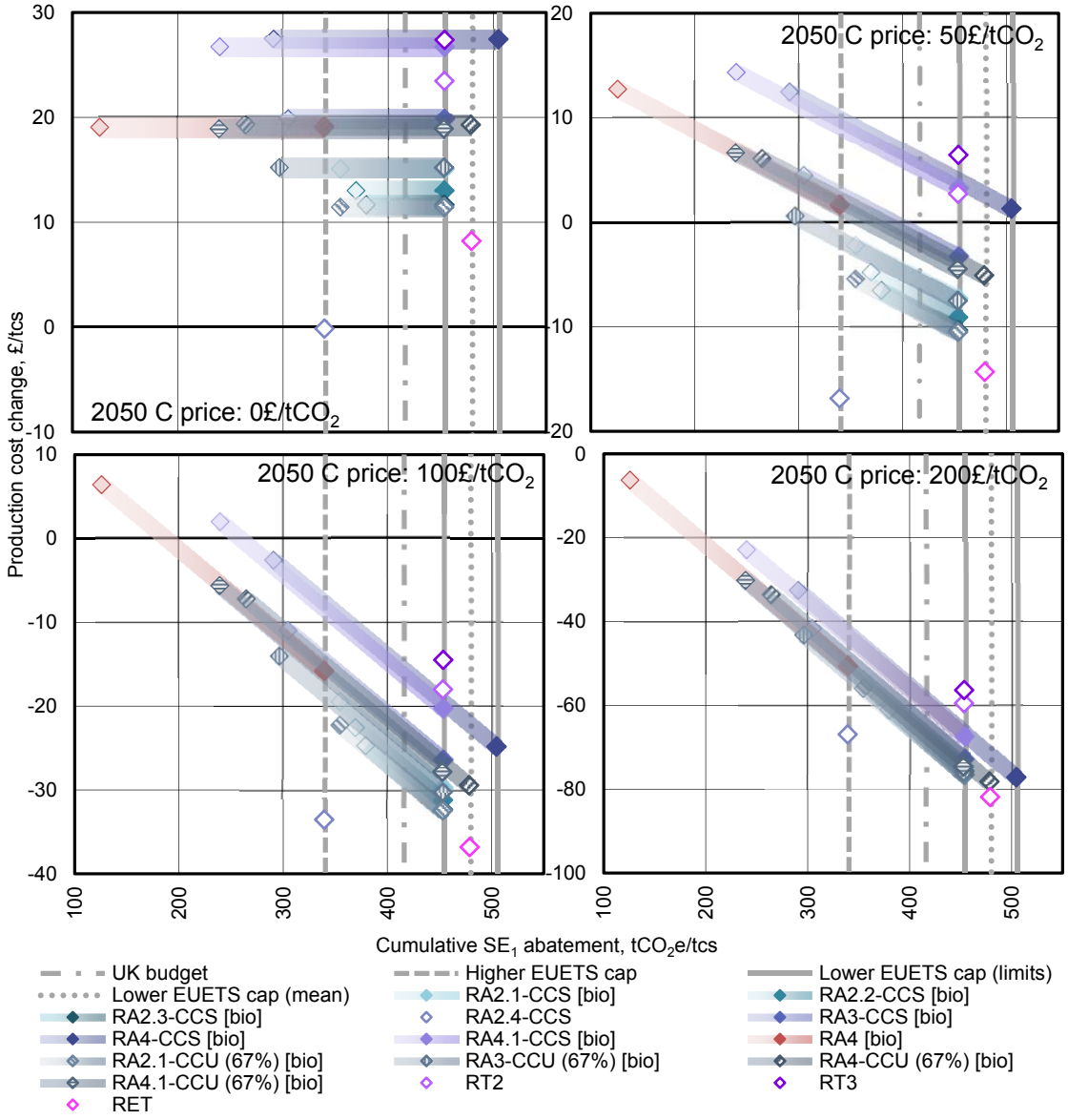

Figure 4-54: Average production cost change and cumulative SE_1 abatement of optimised technology roadmaps of the UK iron and steel sector for increasing steps of emissions trading price

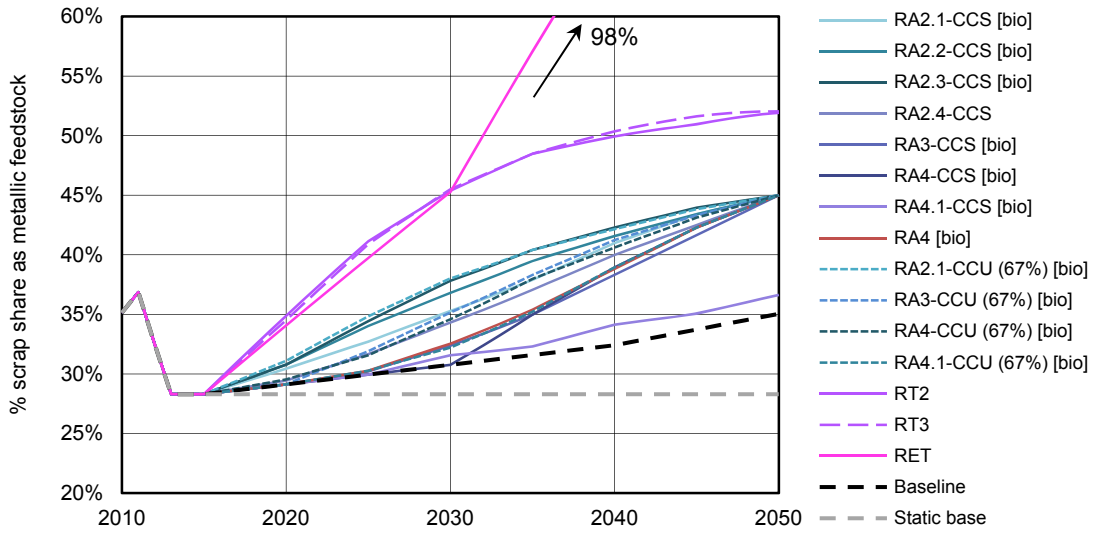

Figure 4-55: Scrap share of metallic feedstock for optimised roadmaps of the UK iron and steel sector

Compared with CCS options, similarly large abatements can be achieved using CCU with higher scrap and charcoal use. However, whether or not CCU abatement applications will become sufficiently available is not a certainty, though they may serve to ameliorate the issue of limited CCS capability.

Excluding biomass and CCUS, only radical process transition can achieve high abatement. RT2 and RT3 do so but with elevated purchases of scrap, increasing most rapidly before 2030. Radical existing process transition (RET) is a complete transition to steel recycling in 2050. This would achieve high abatement at the national level with relatively low average production cost. However, it would require a reversal of the present balance of scrap trade in the UK and thereby curb supply for steel recycling elsewhere.

Should only the higher EUETS cap be implemented to 2050, RA2.4-CCS exemplifies a lower cost route that does not require biomass. RA4 [bio] is an option for meeting the higher cap without radical transition from integrated sites or reliance on CCUS, but still requiring major site transformation with high scrap and biomass use. As these two roadmaps only comply with the higher EUETS cap they fall short of the sector's supposed contribution to meeting the UK budget.

4.6 Discussion

Over the past 40 years production in the UK iron and steel sector has contracted and rationalised significantly, resulting in a considerable fall in energy demand and emissions. Actions such as importing high grade foreign ores, increasing blast furnace fuel injection, recovering reheat furnace sensible energy, and phasing out the ingot casting and OHF methods have also played a part. However, a number of key technologies have not been taken up or have only partially been taken up long after their commercialisation; coke dry quenching, BOFG recovery, and scrap preheating were all in use outside the UK at the time of their recommendation to the sector in the early 1980s through the Government's Energy Audit Series (1982). In another independent study for the Department of Energy (Langley 1984b), it was projected that the sector could reduce its SEC of about 21GJ/tcs in 1981 to 13.5-16.5GJ/tcs in 2000, based on a minimum sector scrap level of 40%. This turned out to be well beyond what the sector actually achieved. In 2000 SEC was 20GJ/tcs and the present baseline is 18.2GJ/tcs, or 17.8GJ/tcs after adjusting for the study's sector structure.

The structural shift in steelmaking route over the years has also favoured the more carbon and energy intensive primary production process over steel recycling. It may seem perverse that the UK produces steel by importing a greater tonnage of coal and iron ore while exporting large volumes of scrap for other countries to recycle. The integrated steelworks is a highly capital-intensive and inflexible production site with long-term investment cycles. By protecting its assets,

the manufacturer is locked into the technology. Closing an industrial site of this scale also has wider economic and societal implications, and would be a national-level decision taken with government consultation (Allwood 2010).

Technological lock-in is a commonly known barrier to transitional change in a system (Scrase and MacKerron 2009) and is present in all of the constructed technology roadmaps to varying extents. The potential cost implications of abandoning the incumbent integrated sites and associated plant was not internalised into the economic appraisal. In examining this further, an adaption factor could be applied in the model to production from the replacement sites. This was not attempted in the assessment due to a lack of detailed knowledge on the related implications. Nonetheless, it is self-evident that the RT roadmap would carry the largest adaption factor, while the RA roadmaps would be less disruptive. This factor, however, may be insignificant given the dominance of resource costs in the sector.

Though the RA-CCS roadmaps entail lower adaption costs, they depend on public investment in CO_2 transport and storage. In a study commissioned by DECC and BIS, transport and storage costs were modelled for UK shoreline terminals (Element Energy 2013). Based on this study, costs would be in the range of 5-30£/tCO_2 for Teesside and Scunthorpe, and 20-35£/tCO_2 for Port Talbot. Weighted by site emissions in 2007, the average cost to the sector is 21£/tCO_2 (or 17.5£/tCO_2 excluding Port Talbot). These costs also could be incorporated into additional model scenarios.

In accordance with lock-in, the vision of the main UK manufacturer (TATA steel) is most reflected in the RA roadmaps. TATA steel was one of the founder signatories of the ULCOS programme and is co-developing the HIsarna concept at its Ijmuiden site in the Netherlands (IEAGHG 2013b). It has also signalled interest in TGR-BF (van Boggelen 2012). However the likelihood of CCS being deployed at scale and in time for the UK sector is uncertain. Not least because TATAs Port Talbot site is not located inside the priority industrial cluster areas so far identified for CO_2 transport infrastructure (DECC 2012, Element Energy 2010a).

The difference in emissions profile between RT and RA-CCS depicts an additional lock-in factor. Under the prospect of timely and publically funded CCS enabling infrastructure, there is an even stronger incentive to maintain production from the integrated sites. Because short-medium term improvement potential from primary production is low, sector emissions cannot begin to fall steeply before CCS becomes available. These higher emissions would need to be compensated for by ambitious deployment rates from 2030. The risk is that CCS will not become available, by which time the sector is many years behind at transitioning to alternative processes. As shown in the optimised roadmaps, however, this risk can be partly offset by transitioning to secondary production earlier and strategically investing in sustainably resourced charcoal and

CCU applications. Although the effective use of charcoal depends on the timely commercialisation of HIsarna.

4.6.1 Evaluation

Despite the detail of this projection assessment, it is not possible to accurately assert the optimum course of action for the sector *ex ante*. The speculative nature of projecting futures in this sector is rooted in the uncertainty of future technology development, fuel prices, scrap availability, and a myriad of unconsidered extraneous factors. Therefore the outputs of the projection analysis conducted should not be viewed as a forecast. A primary purpose of the model is to demonstrate the value of assessing industries using a bottom-up technological database and, in doing so, provide a usable tool for further and wider assessments. For example, control in the model over output and scrap utilisation could assist in a wider assessment of material efficiency futures in the UK. As for the present work, it is recommended that assumptions on all variables are refined with industrial consultation to improve the accuracy of results and avoid conflict with other research in this area, e.g. the Industrial 2050 Carbon Reduction and Energy Efficiency Roadmaps Project.

4.7 Summary and key conclusions

A bottom-up energy and material database was extended and exploited to examine past, present and future resource demands and GhG emissions of the UK iron and steel sector. A number of thermodynamic and economics based methods were utilised to quantify and cost the potential for reducing sector energy and emissions.

Information at the process plant level was sought from primary and secondary sources to characterise in detail the technological structure and status of the sector. Systems of the sector were distinguished and defined in terms of site activity and steelmaking process routes. A multi-level decomposition analysis was conducted to attribute past energy demand and GhG emissions reduction to output, intensity, structural, and other effects. Time-series graphs and waterfall diagrams depicted a dominant output effect, a negative structural effect, and a slow-down in intensity reduction over the period 1990-2007. Energy demand and GhG emissions halved over the period 1990-2010, but reduced by a quarter relative to the base year (1990-2007). Energy and emissions intensity has reduced at less than half the rate since 1990 than the preceding period after the 1973 energy crisis (1973-1990).

A baseline was established and process energy analyses based on IFIAS conventions were conducted to evaluate its wider energy and emissions impact. Thermodynamic improvement potential of baseline processes was determined and Sankey flow diagrams were constructed to map the system for energy and exergy losses. The blast furnace is the most efficient energy conversion process in the sector, but also the largest energy user and a priority target for energy demand reduction. Numerous existing technologies yet to be taken up could reduce a significant

proportion of process energy loss. These include, among others, heat recovery at the coke ovens, sinter plant, and electric arc furnace, and further heat and gas recovery from the basic oxygen furnace. However, the energy and emissions reduction indicated at the process level is significantly eroded by wider aspects of the site which must maximise the use of by-product energy. It was found that the uptake of key BAT technology down to the level of hot-rolling could reduce sector primary energy by 18% and GhG emissions by 12%. Further potential may be available at the blast furnace by optimising chemical transfer to minimise BFG production, or at heat and power facilities for increasing the efficiency of by-product gas use. However, the maximum potential for improvement from existing technologies falls well short of national and European GhG emission reduction targets.

The sector was modelled for technological change over the period 2010-2050. A range of existing and future technology options from incremental retro-fit equipment to radically different process routes were identified and represented at the site level. By combining biomass with CCS, the technical limit of emissions reduction from primary production exceeds 150%. Alternatively, reductions of nearly 100% could be achieved in the future by combining novel electrolysis methods with a decarbonised electricity supply.

A bottom-up techno-economic roadmap projection model was built to analyse the resource use, emissions abatement, and economics of future technologies and technology roadmaps. A detailed appraisal of technological options was carried out and showed that the dynamic economics of future technologies could in some cases be very attractive, though are subject to high variability. The relative economic viability of these technologies is also highly dependent on variable operating costs which are in-turn subject to fuel and material price fluctuations. The emissions trading price is also influential, though some technological configurations of HIsarna and TGR-BF could provide economic saving without an emissions trading price.

A number of 2050 technology roadmaps were constructed and analysed. A novel 'multi-perspective decomposition' of future energy and GhG emissions intensity change from the roadmaps revealed the change attributable to additional and replacement technologies. Cumulative abatement and costs were measured over the 40 years to 2050. A linearly increasing emissions trading price significantly improves the economics of roadmaps relative to the baseline, but exacerbates the absolute economics of the roadmaps and baseline together. In the face of increasing production costs, support mechanisms will be required to supplement and leverage private investment in technology development while reducing risk of carbon leakage.

A further set of optimised technological roadmaps for the sector was constructed to analyse routes to meeting emissions reduction targets in more detail. A number of pertinent factors contributing to risk of failure were also examined. It is suggested that an increased rate of transition to secondary production pre-2030 along with strategic investment in sustainable charcoal and CCU

applications serve to alleviate the risk of inaccessible CO_2 transport and storage technology. In the absence of charcoal or CCUS, a radical process transition leading to higher scrap use would be required. Should this affect scrap trade at the cost of recycling elsewhere, then it would lead to a reduced abatement globally. Wider material efficiency options leading to reduced sector output could play a part in reducing the risk against, and cost of, emissions abatement.

Additional assessment with the techno-economic roadmap projection model could bring additional insights into the sector's future, particularly for wider material efficiency scenarios. Further model runs with refined and updated cost variables would also bring greater robustness to conclusions and inform for various scenarios.

5 The cement sector

In this chapter a bottom-up study of energy demand and GhG emissions in the UK cement sector is made. The chapter compliments a paper submitted to the ICE Journal for which the author was a collaborator. This paper may be referred to in section A9 of the Appendix. Further assessment of improvement potential in the sector was also published in the PhD Thesis (Norman 2013) of another collaborator and supplements the assessment carried out here.

Some of the data on resource flows was gathered from published sources, such as the Cement Sustainability Initiative (CSI) of the WBCSD (CSI 2013), and some from direct correspondence with the Mineral Products Association (Edwards 2011). As with the other sector studies, much of this data was collected under the UED project of the UK Energy Research Centre. The sector covers SIC (07) group 23.51 'Manufacture of cement' which accounts for the bulk of energy use in group 23 'Manufacture of other non-metallic mineral products'.

It is noted that this bottom-up study is of a significantly lower detail than the study conducted for iron and steel. There are two reasons for this. Firstly, the cement sector emits about one third the GhG emissions of the iron and steel sector and demands less than a fifth the energy. It was therefore deemed logical to prioritise research time to the iron and steel sector. Secondly, although both sectors are homogenous, the cement sector incorporates a much less complicated process system. Its modelling therefore has a lower requirement for detail. Despite these differences, the bottom-up approach outlined in section 2.5 is broadly adhered to. Past, present and future aspects of the sector are examined and a baseline model is built and incorporated with additional and replacement technologies into technology roadmap projection model. However, limitations on time has precluded the model's integration with economic data.

In section 5.1, the sector is introduced along with an overview of existing structure. In section 5.2, an energy and emissions baseline for the sector is established. In section 5.3, technologies that could contribute to minimising resource demand and GhG emissions in the sector out to 2050 are identified and their representation for modelling is described. In section 5.4, a bottom-up technology roadmap projection model is introduced and 2050 roadmaps are constructed and assessed. In section 5.5, observations and insights deriving from the chapter's analyses are discussed. In section 5.6, the chapter is summarised and concluded.

5.1 Introduction

The cement sector is a highly energy and carbon intensive sector of industry. Energy demand and GhG emission is focused at the cement kiln. Here the chemical reactions converting limestone into cement clinker take place at high temperatures whilst liberating a high intensity of process CO_2. Clinker is an intermediary product of the sector which is ground and mixed with other

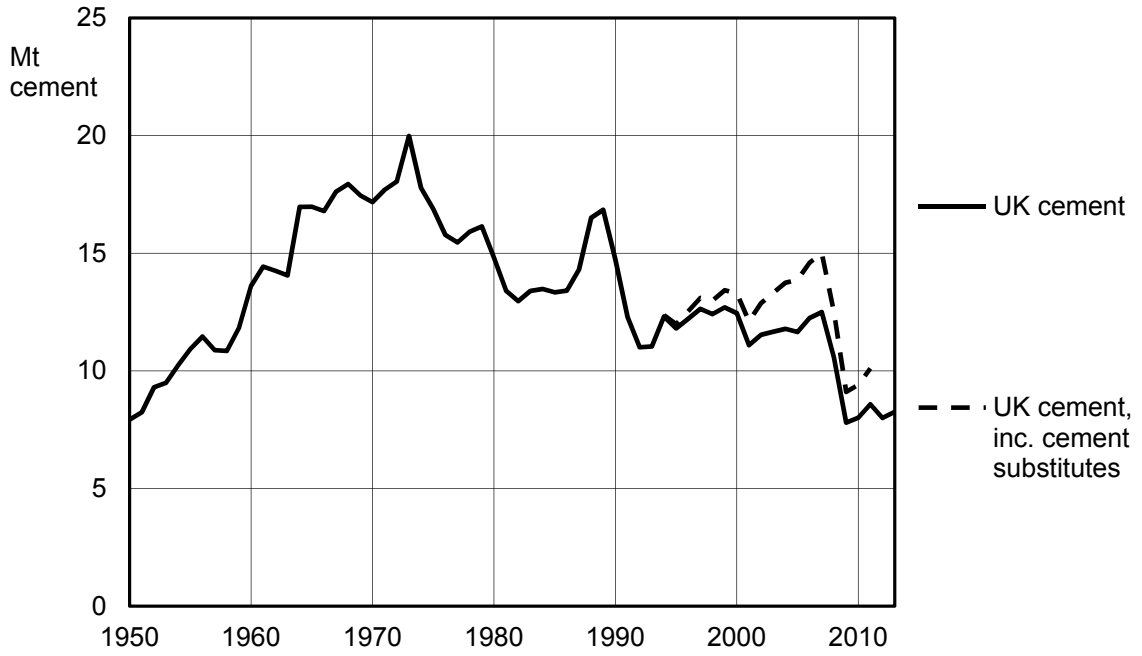

Figure 5-1: Historic UK cement production, 1950-2013, and production of cement after the addition of substitute materials at the concrete mixing site, 1990-2011
(CSI 2013, Edwards 2011)

materials to produce cement. Cement is demanded by the construction industry where it is mainly used in the production of concrete.

Owing to its high resource intensity, the sector has long been efficiency conscious and particularly so after the first energy crisis of the 1970s (Lees and Brown 1989). The sector is also subject to current legislation for reducing GhG emissions but, unlike the iron and steel sector, there is a low risk of carbon leakage. This is because cement has a much lower value per unit of mass making it less economic to transport.

5.1.1 Sector structure and processes

The conventional measure of production for the cement industry is tonnes of Ordinary Portland Cement (OPC). The principle compound of OPC is calcium silicate. Production of OPC follows demand in the domestic construction industry which is in turn related to the stage and state of the economy. Since the boom years of the post-war period up to the 1970s, the UK economy has shifted away from construction and manufacturing. This is depicted in Figure 5-1, which shows the long-term production of cement in the UK. Factory made cement, i.e. before cement substitutes, is contrasted in recent times with total cement production as, unlike in other European countries (Edwards 2011), a significant proportion of high clinker cement is supplied to the concrete mixing site before mixing with further cementitious materials leading to higher volumes of cement.

Production rose steadily to a peak of about 20Mt in 1973, after which a long-term decline began with the first energy crisis and associated economic recession of the 1970s. Passing booms in production and the economy were experienced in the mid-late 1980s and the 2000s. The recent recession significantly affected the construction industry and cement production dropped to below 10Mt, or half the peak of 1973.

The sector has a simple, homogeneous structure characterised by a single production process with a few sequential processing steps. Clinker is the only important intermediary product. Most production sites are located at the limestone quarry providing feedstock to the kiln for producing clinker. In 2010 the UK operated fourteen rotary kilns[28] at twelve sites producing 6.9Mt of clinker and 8Mt of cement (9.4Mt after further material additions).

The principle raw material of the sector is limestone, from which the calcium part derives. Raw material forms include Carboniferous and Jurassic limestone, chalk, shale, and clay (British Geological Survey 2014), where shale and clay are the secondary raw materials providing silica (DCLG 2006). After quarrying, the limestone is crushed into 10cm large rocks before further grinding and preparation with other materials constituting the raw meal (IEA 2009a). This homogenised powder mix is fed into the rotating kiln but usually not before passing through a preheater and a precalciner. The preheater is a series of vertically aligned cyclones utilising waste heat from the kiln flue gas. The dryer the raw material feedstock, the more preheater cyclone stages it is possible to operate. At the bottom of the preheater, the meal descends into the precalciner which is a separate combustion chamber to the kiln in which calcium carbonate decomposes into calcium oxide and CO_2 at approximately 900°C (European Commission 2010b). After the calcination stage, the meal enters the rotating kiln in which calcium oxide reacts with secondary materials at 1500°C to form the small nodules of material referred to as clinker (ibid.). The clinker is promptly cooled before being ground and blended with other materials such as gypsum, pulverised fly ash and blast furnace slag.

There are variations on the basic process route up to the calcination stage. The process undertaken is broadly classed as either 'dry' or 'wet' depending on the availability of limestone and chalk respectively. In the dry process raw materials are fed into a preheater/precalciner kiln in a dry and ground form. In the wet process water is added to the raw materials during grinding to form slurry (European Commission 2010b). There are also intermediary classifications, semi-wet and semi-dry, for which the raw materials are first formed into pellets of specified moisture content. Efficient semi-wet or semi-dry processes with grate preheating are better known as Lepol kilns.

[28] This number remained after the closure of four kilns over the 2008-09 period and precedes the decommissioning of a small kiln at the South Ferriby site in 2012.

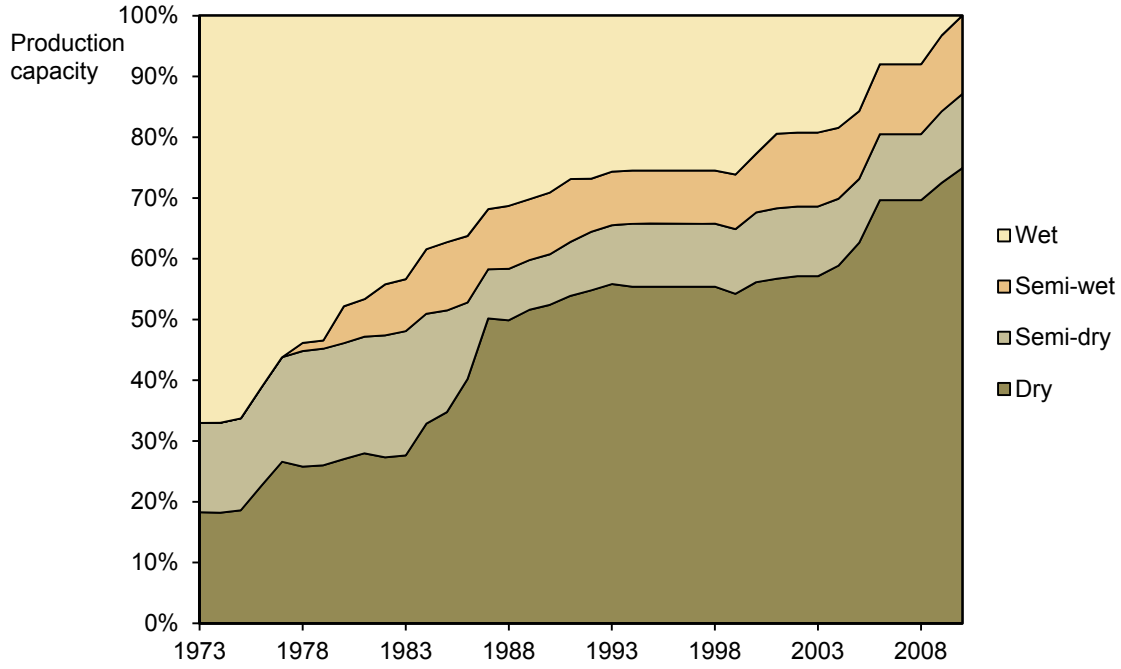

Figure 5-2: Proportion of clinker production capacity in the UK cement sector, 1973-2010, derived from Moore (2011)

Because feedstock moisture content is lower for the dry process, less energy is required in drying the materials and higher process energy efficiencies may be achieved. The balance of dry and wet process routes making up the sector therefore influences average sector energy intensity and related GhG emissions. Since 1973 the sector has steadily shifted towards dryer processing and in 2010 clinker capacity was shared by eleven dry kilns (73%), three semi-dry kilns (11%) and one large semi-wet kiln (13%) (Edwards 2011). Figure 5-2 shows this process transition over the period 1973-2010.

5.2 Sector baseline

Figure 5-3 is a Sankey diagram illustrating the main split of energy within the sector as it has been modelled. Nearly all fuel demand is used at the kiln system (including the precalciner). All electricity demand is purchased from the grid. This is unsurprising as it is not viable to use CHP given the amounts of waste heat already provided by the kiln system. Though it may be possible to use surplus process heat for onsite electricity generation, this is not currently practiced in the sector.

Table 5-1 summarises thermal energy and GhG intensities at the level of kiln type in 2010. 'Instantaneous SEC' is based on generic figures in literature according to process type and equipment (Smidth 2006). 'Informed SEC' is based on more detailed technical knowledge via consultation with an industry expert (Moore, D., cementkilns.co.uk, pers. corr., March 2012).

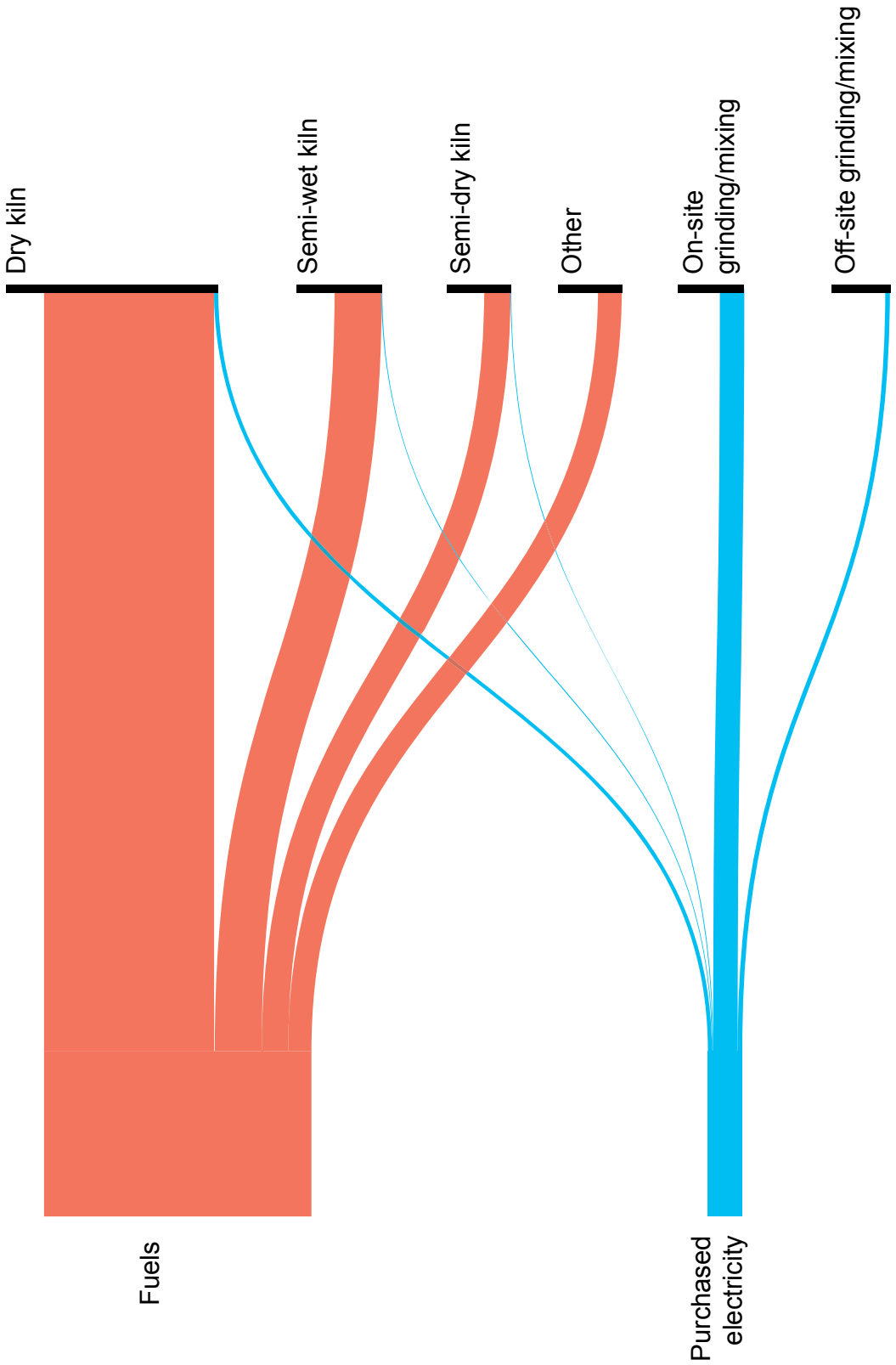

Figure 5-3: Sankey diagram of process-level energy flows in the UK cement sector in 2010

Location	Kiln description	Kilns in operation	Feedstock, kt	Output, kt				Specific energy, GJ/t output				Specific GhG emission, tCO_2e/t output			
			Limestone and clay	Description	Clinker capacity	Clinker production (60% load factor equally distributed)	Cement, or site cement equivalent, production	Instantaneous SEC_f (weighted kiln SEC)	Typical SEC_f (weighted kiln SEC)	SEC_f (reallocated kiln SEC)	SEC_e	Combustion emission	Calcination emission	Direct emission (Scope 1)	Scope 1-2/3 emission (Inc. elec. gen. and delivery)
Rugby	Semi-wet, 2-stage preheater, precalciner	1	1,097	Clinker	1,460	919	1,076	4.60	4.60	4.79	0.085	369	525	894	906
South Ferriby, Cookstown	Semi-dry, Lepol grate	3	976	Clinker	1,300	818	958	3.60	3.58	3.73	0.085	287	525	812	824
Hope, Derrylin, Aberthaw	Dry, 4-stage preheater	4	1,727	Clinker	2,300	1,447	1,694	3.39	3.65	3.80	0.085	293	525	818	830
Tunstead, Ketton, Cauldon	Dry, 4-stage preheater, precalciner	3	2,295	Clinker	3,056	1,923	2,251	3.17	3.61	3.76	0.085	263	525	789	801
Dunbar, Padeswood, Ribblesdale	Dry, 5-stage preheater, precalciner	3	2,073	Clinker	2,760	1,737	2,033	3.00	3.26	3.39	0.085	261	525	786	799
UK	All kilns	14	8,169	Clinker	10,876	6,843	8,012	3.42	3.66	3.81	0.085	293	525	819	831
UK	Cement manufacturing site	14	8,169	Cement	10,876	6,843	8,012	-	-	3.57	0.426	276	449	724	786
UK	Sector	14	8,169	Cement	10,876	6,843	9,401	-	-	3.05	0.418	235	382	617	678

Table 5-1: Production, energy and GhG emissions baseline of the UK cement sector in 2010

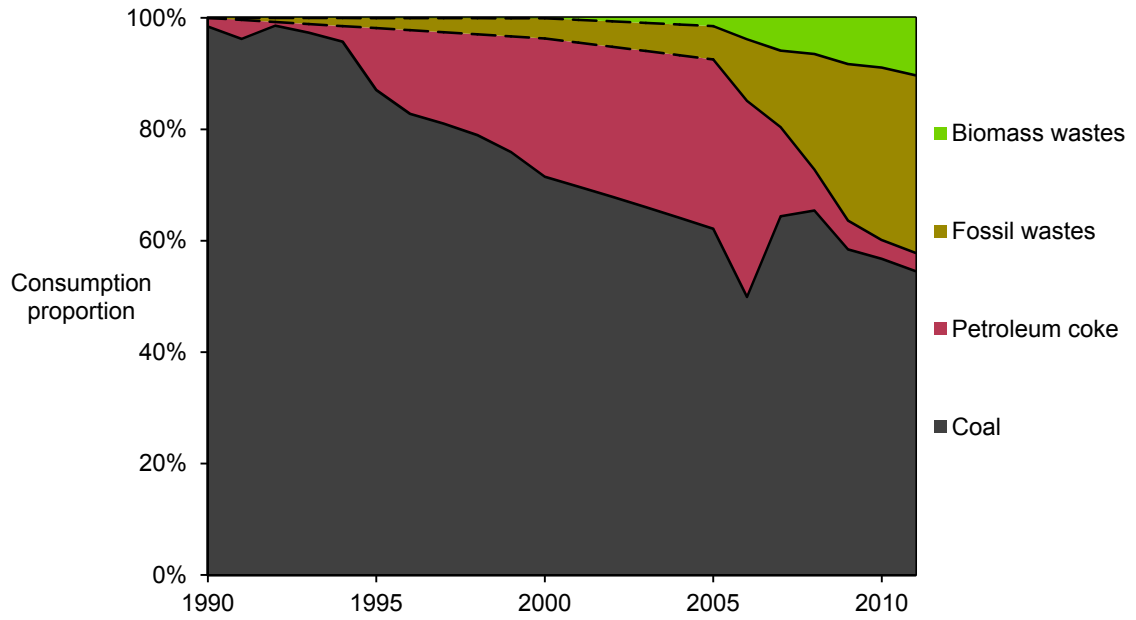

Figure 5-4: Kiln fuel split in the UK cement sector, 1990-2011 (CSI 2013)

Instantaneous SEC refers to the hypothetical performance of a kiln running smoothly under optimum operating conditions. In reality there is an energy penalty relating to a number of operating factors, in particular to kiln start-ups and shutdowns. The SECs of individual kilns informed from Moore (2011) were quoted as typical and could reasonably be expected during a 'good year'. However, output in 2010 was poor with the sector's 14 operational kilns averaging a load factor of 60%. According to CSI (2013) average kiln SEC was 3.81GJ/t in 2010 which equates to about 10% above instantaneous SEC and 4% above typical SEC.

Another potential source of discrepancy between the bottom-up calculation and actual SEC in 2010 is in the weighting of kiln level performance by capacity as opposed to real production. Production data at the kiln-level is commercially sensitive and was therefore not available for the analysis. Nonetheless, potential error arising from this would be insignificant.

Direct combustion GhG emission was calculated by applying to SEC the kiln fuel split. Figure 5-4 shows the trend in kiln fuel split over the period 1990-2011. The dashed lines represent linear interpolations between years of data availability, i.e. 1990, 2000, 2005-2011 (CSI 2013). Comparison with the fuel specifications of individual kilns operating over the period suggests that this is a suitably accurate interpretation (Environment Agency 2008). Thought it is clear that coal still dominates, fuels have increasingly been substituted by alternative waste derived fuels in recent years. Waste fuels are split into fossil wastes and biomass wastes. The former mostly consists of scrap tyres, waste oils and solvents, plastic refuse, and mixed industrial wastes. The latter mostly consists of animal meal and bone, dried sewage sludge, waste wood and paper refuse. In 2010 about 40% of kiln thermal energy demand was waste derived and 20% of this was biomass.

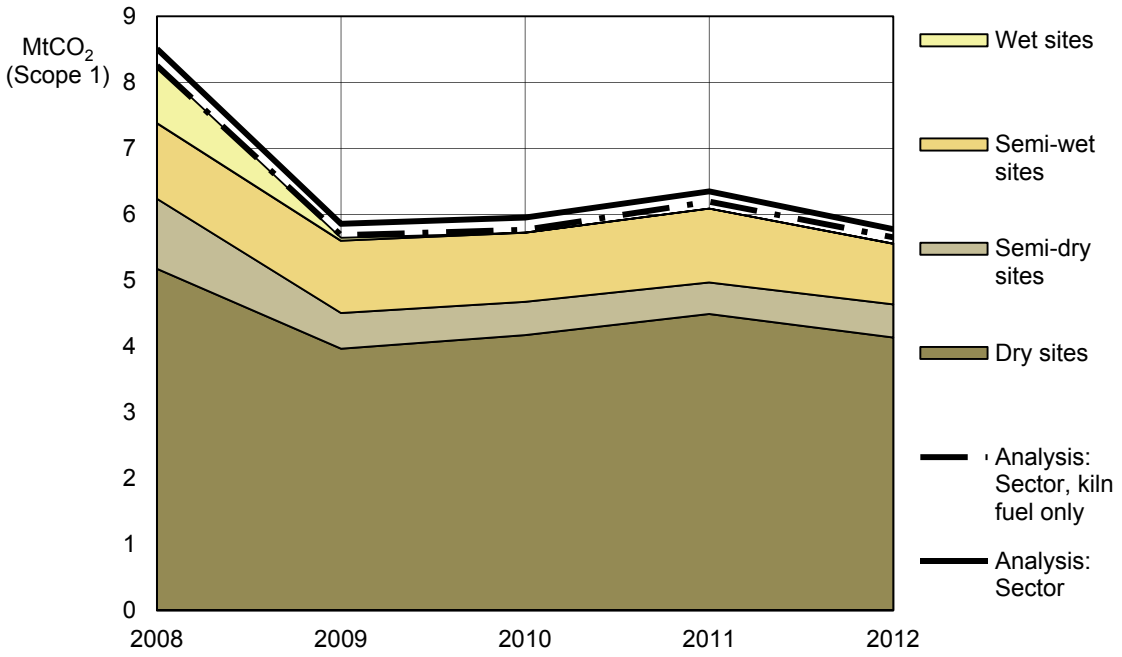

Figure 5-5: Comparison of calculated emissions with emissions verified for trading under phase II of the EUETS for UK cement sector (Environment Agency 2013)

Process GhG emissions are supplied by MPA to the GHGI and were 3.79MtCO_2 in 2010 (DECC 2014g). Using the emissions factor of 0.44t/tCO_2 for limestone (IPCC 2006), it is estimated that UK kilns consumed 8.6Mt of limestone and chalk in 2010. Including limestone consumed as direct mineral additions to cement, consumption was 9Mt (CSI 2013).

In Figure 5-5, calculated direct CO_2 emissions are compared with trading emissions verified for UK cement installations under the EUETS. There is good correspondence between verified and calculated kiln emissions. Verified emissions represent about 96% of direct sector CO_2 emissions, and 95.5% of direct sector GhG emissions.

Table 5-1 also shows figures specific to cement production. The production of clinker per unit of cement product can be reduced by blending it with higher amounts of substitute materials such as pulverised fly ash (PFA) or ground granulated blast furnace slag (GGBFS). This is somewhat analogous to the substitution of iron with scrap at the BOF in the iron and steel sector. In 2010 clinker substitution was about 12% including direct additions to clinker for OPC and blended cement varieties. Including clinker substitute additions to concrete, effective cement production is increased and overall clinker substitution was 27%.

5.3 Technological identification and representation

Identified technologies and measures are categorised into the following: energy efficiency, fuel switching, clinker substitution, carbon sequestration, and cement substitution. The technologies were chosen on the basis that they may feature in the UK cement sector in the time to 2050.

5.3.1 Energy efficiency

Current kiln BAT is defined as a dry rotary kiln with 6-stage cyclone preheater and precalciner yielding an instantaneous fuel SEC of 2.9GJ/t (European Commission 2010a, Smidth 2006). Kiln BPT is defined as the best performing technology presently in operation in the UK. This is as BAT but with a 5-stage cyclone preheater and instantaneous fuel SEC of 3GJ/t.

Future potential beyond BAT may be available through process change. The fluidised bed kiln (FBK) is under development by a Japanese company and a 1kt/d plant has been successfully demonstrated in China (NEDO 2006). The technology incorporates a novel 'self-granulation process' enabling improved granulation control via partial raw material agglomeration. The system operates with up to 0.3GJ/t clinker less energy requirement (ECRA 2009a).

Energy efficiency has been modelled in terms of additional and replacement kiln technology. Equipment upgrade options include: installing a grate cooler where a planetary cooler is present (saving 0.2GJ/t clinker); installing a fifth, a sixth, or a fifth and sixth preheater stage (average saving 0.1GJ/t clinker per stage), and installing a precalciner where a precalciner is not present (saving 0.2GJ/t clinker). Replacement options include: BPT kiln, BAT kiln, and FBK kiln with instantaneous SEC 3GJ/t clinker, 2.9J/t clinker, and 2.6GJ/t clinker respectively. The energy saving depends on the kiln being replaced and is the difference in instantaneous SEC (see Table 5-1). Saving from replacement kilns are also relative to the baseline after equipment upgrades so as to avoid double counting.

5.3.2 Fuel switching

It is technically feasible for a cement kiln to be fired by 100% alternative waste derived fuel (ECRA 2009a). By 2050 the sector aims to derive 80% of thermal energy demand at the kiln from locally sourced waste and for half of this to be biomass (MPA 2013a). This target may become more challenging with waste declassification through 'End of Waste Protocols and Publically Available Specifications' (ibid.), which may divert materials from the waste stream. Greater competition with the power generation sector is also anticipated.

Fuel switching has been modelled to provide control over the substitution level from alternative waste derived fuel and the biomass content of that fuel.

5.3.3 Clinker substitution

MPA suggest that cement clinker substitutes could increase to 30% by 2050, which would equate to an overall substitution of nearly 45% of the clinker at the concrete mixing site (MPA 2013a). The degree to which clinker may be substituted is limited by its influence on physical properties, which are in turn subject to the requirements of the construction sector. Further limitation will be set by the availability of GGBS and PFA, the former dependant on blast furnace ironmaking and

the latter on coal fired power generation. Both of these sources in the UK are likely to reduce in activity over the period to 2050. These substituting materials are collectively referred to as supplementary cementitious materials (SCMs). Clinker substitution has been modelled to substitute factory cement with further additions of GGBS and PFA. The ratio of GGBS to PFA added at the concrete mixing site in 2010 was 3:1 and this ratio is assumed to be maintained.

5.3.4 Carbon sequestration

Research for the development and demonstration of capture technologies in the European cement sector is being conducted by ECRA. Under phase I of the project, a scoping exercise assessed the merits and demerits of identified technologies: pre-combustion, post-combustion, oxyfuel systems, and carbonate looping (ECRA 2009b). Consequently, the feasibility of post-combustion and oxyfuel technology was assessed in more detail under phase II of the project. A detailed techno-economic study of these technologies was also conducted for the IEA Greenhouse Gas R&D Project (IEAGHG 2008).

Post-combustion CCS is an 'end-of-pipe' technology and could be retrofitted to existing plants involving replacement of the stack with all other components unchanged. Variants include chemical absorption, membrane technologies, carbonate looping and mineral adsorption. Amine absorption is seen as the most promising of these and many pilot and demonstration projects for the power sector have been launched to date, with commercialisation anticipated post-2020. By this time ECRA aim to have mounted a full-scale demonstration project on a cement plant (ECRA 2009b). Two important disadvantages for capture at cement plants relative to power generation plants are: low economies of scale and absence of large surplus amounts of low-grade waste heat. As such, a significantly high level of additional energy is demanded for solvent regeneration during the process that separates CO_2. With a SEC of about 3GJ/tCO_2, post-combustion would equate clinker production efficiency to that of a small wet kiln from the mid-1970s, or about 6.5GJ/t (Langley 1984b).

Oxyfuel technology involves the combustion of oxygen and recycled CO_2 instead of air, resulting in a relatively pure CO_2 exhaust for capture. It is envisaged that commercial availability could occur in 2025 (IEA 2009a). Retrofitting is unlikely as it would necessitate the rebuild of most of the existing plant's core components. An oxyfuel retrofit could, however, be confined to the precalciner, which would limit capture. Under the latest phase of the ECRA CCS project, R&D for oxy-fuel combustion involved laboratory scale testing and process modelling (ECRA 2009b).

Considerable technical and economic challenges are associated with the above technologies. MPA assumed two scenarios in 2050: one in which 3MtCO_2 is captured and one in which there is no deployment of CCS. The former scenario equates to around a half of cement production being equipped with CCS.

CCS has been modelled to provide numerous equipment and configuration options. Included are the options modelled in the abovementioned techno-economic study (IEAGHG 2008): MEA post-combustion; MEA post-combustion with over-the-fence waste heat; KS-1 post-combustion; oxyfuel precalciner combustion; oxyfuel precalciner combustion co-located with oxyfuel combustion power plant. KS-1 is a proprietary amine solvent capable of a 25% lower steam demand. Oxyfuel technology was modelled as applicable to the precalciner or the entire kiln system, where oxygen requirement has been scaled up from the IEAGHG study in proportion with process fuel requirement. If co-located with a power plant equipped with the same technology then energy and cost savings can be derived from consolidating oxygen production and CO_2 compression facilities. The post-combustion options without over-the-fence steam use an onsite CHP plant to meet steam demand. Electricity generated is used to meet demand at the site with a small surplus being exported to the grid. The model provides the option to switch CHP fuel from coal to biomass, or any blend of the two. Capture efficiency is 85% for post-combustion technologies, 62% for precalciner oxyfuel technology, and 95% for the full application of oxyfuel technology. Equipment capture efficiency can be adjusted in the model.

5.3.5 Cement substitution

In recent years there has been considerable interest in the development of novel low energy, low CO_2 cements. The range of options have been well examined (Gartner and Macphee 2011, Juenger et al. 2011), and MPA have commented on the potential implications for the UK cement industry (Taylor 2011). The most promising products identified are summarised in Table 5-2. Other notable options are being developed by companies Calera (Constantz 2010) and Calix (Calix 2011), but detailed product or process information has not yet been published for these.

Novacem™ is a magnesium oxide based cement derived from common magnesium silicate rocks and was spun-out from research at Imperial College London, and later sold to Australian based company Calix. Special magnesium carbonates, added to control setting and hardening properties, can absorb CO_2 from the process and atmosphere, and so theoretically enable the manufacture of net-CO_2 negative cement (Gartner and Macphee 2011). The first pilot plant was constructed in 2010 and a semi-commercial plant is expected from around 2017/18 (Novacem 2012). It is also claimed that the process could be retrofitted to existing cement plants, albeit a major refit (Miles 2012). There is an abundant and reasonably well distributed accessible global resource for magnesium silicate: about 10 trillion tonnes in 16 of the top 20 cement markets (Velandia et al. 2011a). However, this is not the case in the UK and any meaningful domestic production would require the import of raw materials. Though Norway is the world's largest producer of the principle source of magnesium silicate, Olivine, (Kogel et al. 2006), shipment of this resource would nonetheless have a probably significant effect on future production costs, which are already uncertain (Gartner and Macphee 2011).

Product	Cement	Principle raw materials	Claimed emissions reduction	Process temperature	Degree of technical change/Stage of development
Novacem™ (Calix, Australia)	Magnesium oxide	Olivine, Serpentine	60-113%[29] (Velandia et al. 2011b)	700˚C	Radical/Pilot demonstration
E-Crete™ (Zeobond, Australia)	Alkali-activated (Geopolymer)	Kaolin, Industrial wastes (e.g. PFA and GGBS)	80-90% (Duxson et al. 2007)	Room temperature (Metakaolin: 800˚C)	Radical/Small-scale commercialisation
Celitement™ (Celitment, Germany)	Partially prehydrated Calcium silicate hydrate	Limestone, Quartz	50% (Stemmermann et al. 2010)	150-210˚C (Quicklime: 1000˚C)	Radical/Pilot demonstration
Aether™ (Lafarge, France)	Belite-calcium sulphoaluminate-ferrite	Limestone, Kaolin, Gypsum	20-30% (Walenta 2011)	1225-1300˚C	Major/Industrial scale demonstration

Table 5-2: Summary of alternative cement technology

E-Crete™ contains alkali-activated cement and was commercialised in 2008 by Australian based company Zeobond. The cement is made with limited processing via the mixing of solid alumino-silicate powders (in particular metakaolin, fly ash and blast furnace slag) and an alkaline activating solution forming a network structure which has given it the name 'geopolymer' or 'inorganic polymer' (Juenger et al. 2011). If mixed correctly, the cement can set and harden at room temperature. This has been demonstrated at large scale (van Deventer et al. 2010). E-Crete™ was first produced on a small industrial scale in 2006 and Zeobond commenced commercial supply of its product soon thereafter (Duxson and Provis 2008, Von Weizsäcker et al. 2009). The technology has since been licensed to a number of companies around the world including one in the UK (Geopolymer Institute 2012). The cement has also been proven to give relatively suitable if not superior physical properties to that of OPC (Duxson et al. 2007). However, these properties are vulnerable to the application of adequate curing regimes and there is uncertainty over long-term durability (Duxson et al. 2007, Juenger et al. 2011). It should also be noted that the use of fly ash and blast-furnace slags in this case conflicts with the measure of clinker substitution which would compete for raw materials.

[29] The range given depends on fuel mix used for the process. 113% reduction potential is true in the case of biomass fuel with zero CO_2 emissions assumed. If the EF for kiln fuel substitution is used, this figure reduces to 94%.

Recently developed by researchers at the Karlsruhe Institute of Technology in Germany, Celitement™ represents a more efficient use of the properties associated with the calcium silicate hydrate (C-S-H) phase: the most important binder phase of OPC (Gartner and Macphee 2011, Stemmermann et al. 2010). Instead a 'precursor phase' of C-S-H coats the surface of a relatively inert silica-rich filler such as quartz. The precursor is formed via the reaction between quicklime, silica and water under autoclave conditions. The pilot demonstration plant commenced operation in late 2011 to develop the product up to the stage of practical trial. The first industrial, or reference, plant was planned for 2014. Similar autoclave technologies are already used in the manufacture of aerated concrete or sand-lime blocks, so future production facilities may only depend on modifications to well-established technology. Structural and chemical characterisation of the product is complex and suitability as a mass-scale OPC substitute is yet to be investigated.

Aether™ is a recent development by Lafarge which combines the established science of reactive belite (Chatterjee 1996) and calcium sulfoaluminate (CSA) (Sharp et al. 1999) cements to produce synergistic, intermediate clinker arrangements comprising belite, calcium sulfoaluminate (ye'elimite) and calcium aluminoferrite phases (Li et al. 2007). The lower level of calcium carbonate in the feedstock and production of different clinker phases to OPC leads to lower process CO_2 emission and thermal energy requirement respectively. With a lower proportion of ye'elimite than in standard CSA-belite clinkers (manufactured and used on an industrial scale in China for over 30 years), the product can be manufactured without the use of bauxite, which is a relatively expensive raw material and notably scarce in the UK (Kogel et al. 2006). The problem of slow late-strength development is also addressed with the inclusion of additional minor ingredients. The first industrial-scale demonstration was completed in 2011 in an existing rotary OPC kiln in France and further testing in a second kiln has been conducted.

Alternative cements have been modelled to enable substitution from any, or any combination, of the identified options. Aether is modelled for manufacture in existing kilns at the level of clinker and does not conflict with kiln efficiency, fuel switching, and clinker substitution measures. CCS also applies to plants producing Aether and control is given over what proportion of CCS is applied to Aether over OPC. The other alternative cements are modelled to replace at the level of cement so are not compatible with kiln efficiency of clinker substitution. However, control is provided for substitution of process fuel with biomass.

5.4 Technology roadmap assessment

In this section a technology roadmap assessment is conducted for the potential deployment of identified technologies out to 2050. The extent of resource demand and GhG emissions reduction is therefore quantified and investigated. A bottom-up technology roadmap projection model was built to conduct the assessment. For further detail refer to section A6.1 of the Appendix. Supplementary model outputs may be referred to in section A6.1.1 of the Appendix.

5.4.1 Roadmap modelling

The cement industry has itself been active in the area of technology roadmapping at both the global and the UK level. Through the WBCSD's CSI, the cement sector led the way among industrial sectors in setting out a clear technology roadmap for long-term GhG abatement. Data collected under the CSI was used with scenario analysis of the IEA Energy Technology Perspectives (ETP)–MARKAL model to map a mitigation pathway to halving global cement emissions by 2050 (IEA 2009a). The WBCSD/IEA roadmap also draws on a compilation of 38 technical papers produced by the ECRA (2009a). The model projects an ambitious uptake of CCS involving 220-430 sites worldwide capturing up to 45% of sector emissions. However, though the roadmap can be utilised in providing global and regional context, it is not sufficient to inform policy at the national level. Domestic information provided for the roadmap analysis from the UK via the CSI's 'Getting the Numbers Right' (GNR) database is also incomplete in certain key areas, e.g. kiln specification (CSI 2013). Moreover, there is no consideration of a non-CCS outcome and no attempt has been made to model the potential of alternative cements.

Then the British Cement Association (BCA), MPA launched its 'Carbon Strategy' in 2005 detailing short-medium term action targets. Following this, the association recently published the 'MPA Cement GhG Strategy: Roadmap to 2050' (MPA 2013a). The projected roadmap echoes the WBCSD/IEA roadmap on CCS dependency though with greater acknowledgement of CCS unavailability and alternative cements. However, the scenario in which there is no CCS deployment assumes the sector takes no alternative action. Abatement in this case is low over the 2010-2050 period and alternative cements are limited to a 5% encroachment of the market for OPC. Generally the assessment is simplistic from a modelling perspective and, as with the WBCSD/IEA roadmap, lacks transparency.

5.4.2 Baseline projections

The projected baseline is affected by sector output, grid decarbonisation, and deployment of BPT/BAT. It is assumed that the grid will decarbonise by 85% over the period 2010-2050 (see analysis in section A4 of the Appendix).

In keeping with the projections of WBCSD/IEA for Europe and of MPA for the UK, the general trend in cement production out to 2050 is assumed to be stagnant. Annual cement production level is assumed to be 10.5Mt and was estimated based on the allocation of emissions allowances for the sector in phase III of the EUETS (DECC 2014m). Allocation of emission from the sector in 2013 is based on the average annual emission over phase II (2008-2012). Assuming emissions intensity in 2012 moves pro-rata with the rate of reduction in allocated emissions, then cement production equates to about 11Mt. After adjusting the phase II average

for kilns that were retired over that period, and therefore not applicable to phase III, production equates to about 10.5Mt.

Baseline action towards BAT clinker production is a transformation of the whole sector to BPT kilns. This involves the replacement of the sector's semi-dry and semi-wet kiln capacity at retirement age with 5-stage preheater and precalciner dry kiln capacity. Existing dry kilns without grate coolers, precalciners, or a fifth stage of preheating are incrementally upgraded to the BPT level.

5.4.3 Roadmaps

Numerous illustrative technology roadmaps to 2050 are described in Table 5-3 and shown alongside GhG emissions accumulated over specified policy periods. For more detailed figures on the deployment of technologies and measures for each roadmap refer to section A6.1 of the Appendix. Figure 5-6 shows sector GhG emission pathways of the assessed roadmaps and the projected baseline. Graph A includes direct emissions (scope 1) and graph B includes direct and indirect emissions (scope 1-2/3), which encompasses electricity generation and delivery. Also shown are the decarbonisation pathways of the higher and lower EUETS caps and the UK budget.

It is evident that sector emissions dropped sharply on two occasions since 1990. In both instances these reductions came as a result of a drop in cement production which had in turn resulted from economic recession and lower demand in the UK construction sector. Production level did not return after the first fall and is not projected to return after the second. As a result the cement sector today is relatively well placed to meet the EUETS caps and its share of the UK budget. This is reflected in the EUETS by a vast over allocation of emissions allowances in phase II (DECC 2007a), of which the resulting surplus is banked for use in phase III. The supply of new allowances in phase III and beyond is also shown in the Figure 5-6 where the emissions cap reduction rate increases from 1.74% in phase III to 2.2% from 2021. The steeper rate translates to the minimum requirement of the lower long-term cap which stipulates a 43% reduction in 2030 from the level in 2005 (European Commission 2014a).

A large surplus of allowances undermines the proper functioning of the carbon market and could lead to less predictable or economic outcomes. In the short-term, the European Commission has 'back-loaded' the number of allowances available in phase III to 2019-2020, though this will not reduce the total supply over the period (European Commission 2014e). To deal with the structural surplus in the system, further action will take place from 2021. Firstly, the commission has proposed the legislation of a market stability reserve that would function according to predefined rules, automatically compensate for such issues, and add greater flexibility to the supply. Secondly, the overall supply will be curbed by the increased cap reduction rate and further

restrictions on the use of international carbon credits. However, the associated reduction of 13MtCO_2 over the period 2013-2050 does not make up for 20MtCO_2 of allowances over-allocated to the sector in the UK in phase II. In contrast with the iron and steel sector, the UK budget as applied here equates to the same limit on emissions as imposed by the maximum extent of the lower EUETS cap after 2005, which is 265MtCO_2.

All roadmaps lead to a cumulative emission beneath the lower long-term EUETS cap and even the baseline falls within the range of this cap. Relative to the supply of new allowances from the beginning of phase III, however, only RA-CCS [bio-CHP] and RT2-CCS [bio-CHP] emit near or below the total. In RA-CCS3 a more efficient proprietary solvent is used for CO_2 separation than in RA-CCS. Perversely this improvement leads to a diminished abatement in RA-CCS3 [bio-CHP] because the lower energy demand requires a smaller CHP system and therefore a reduced opportunity to store CO_2 extracted from the atmosphere during biomass growth. The same is true in the case of over-the-fence waste heat utilisation (RA-CCS2) or the oxyfuel combustion CCS plant (RA-CCS5). However this does not mean the more efficient CCS technologies are inferior. On the contrary, they are more economically viable and would leave more biomass available for use with CCS equipped installations in other sectors.

The FFT roadmap is a close representation of the technical limit to improvement in the sector without the use of innovative process technologies or CCS. The shallower gradient of abatement relative to the EUETS 1.74% declining cap is indicative of the limited room available for improvement in the sector from existing technologies and measures. The existing opportunities are limited not just because efficiency and fuel switching only attend to combustion emissions, but also because clinker substitution can have a negative influence on product quality at high levels of substitution. The prospect of a synergy between clinker substitution and Aether clinker, however, is not inconceivable if Aether proves itself a superior clinker for certain properties. The roadmap of FFT/RT2 combines the ambitious trajectory for existing measures with a transition to Aether cement and shows how such a route could achieve similar cumulative abatement to the non-biomass CCS roadmaps.

	Energy efficiency (2010-2050)	Fuel switching (2010-2050)	Clinker substitution (2010-2050)	CCS (2030-2050)	Alternative cements (2025-2050 aether; 2030-2050 others)	E_1, $MtCO_2e$ (2011-2050)	UK budget E_1, $MtCO_2e$ (1991-2050) [target: 429]	Lower EUETS cap E_1, $MtCO_2e$ (2006-2050) [Target: 266]	EUETS alloc. E_1, $MtCO_2e$ (2013-2050) [Target: 154]	Emissions caps/allocation cap met?
Baseline	Improvement to BPT rotary kiln	Increase to 67% waste fuel; of which 25% biomass	Steady increase from 27% to 35%	-	-	234	437	274	221	No/No
RA	Improvement to equal share of BPT and BAT rotary kiln	Increase to 80% waste fuel; of which 50% biomass	Increase to 40%	-	-	217	420	258	205	Yes/No
RA-CCS				50% MEA post-combustion	-	196	399	237	184	Yes/No
RA-CCS [bio-CHP]						171	375	212	159	Yes/No
RA-CCS2				50% MEA post-combustion with waste heat import	-	193	396	234	180	Yes/No
RA-CCS3				50% KS-1 post-combustion	-	195	398	236	183	Yes/No
RA-CCS3 [bio-CHP]						177	380	217	164	Yes/No
RA-CCS4				50% Oxy-fuel combustion applied to precalciner only	-	199	403	240	187	Yes/No
RA-CCS5				50% Oxy-fuel combustion	-	190	393	231	178	Yes/No
FFT		Accelerated increase to 90% waste fuel; of which 75% biomass	Accelerated increase to 45%	-	-	202	405	243	190	Yes/No
RT	Improvement to equal share of BPT and BAT rotary kiln; 20% of capacity to FBK	Increase to 80% waste fuel; of which 50% biomass	Increase to 40%	-	33% Aether, 10% Celitement, 10% geopolymer, 10% mgO	203	406	243	190	Yes/No
RT2				-	80% Aether	209	412	250	196	Yes/No
RT2-CCS				50% MEA post-combustion (30% to aether plants)	80% Aether	191	394	231	178	Yes/No
RT2-CCS [bio-CHP]						166	369	207	154	Yes/Yes
RT3				-	40% Celitement	206	410	247	194	Yes/No
RT4				-	40% geopolymer	200	403	241	188	Yes/No
RT5				-	40% MgO	204	407	245	192	Yes/No
FFT/RT2		Accelerated increase to 90% waste fuel; of which 75% biomass	Accelerated increase to 45%	-	80% Aether	195	398	236	182	Yes/No

Table 5-3: Descriptions and abatements of technology roadmaps of the UK cement sector

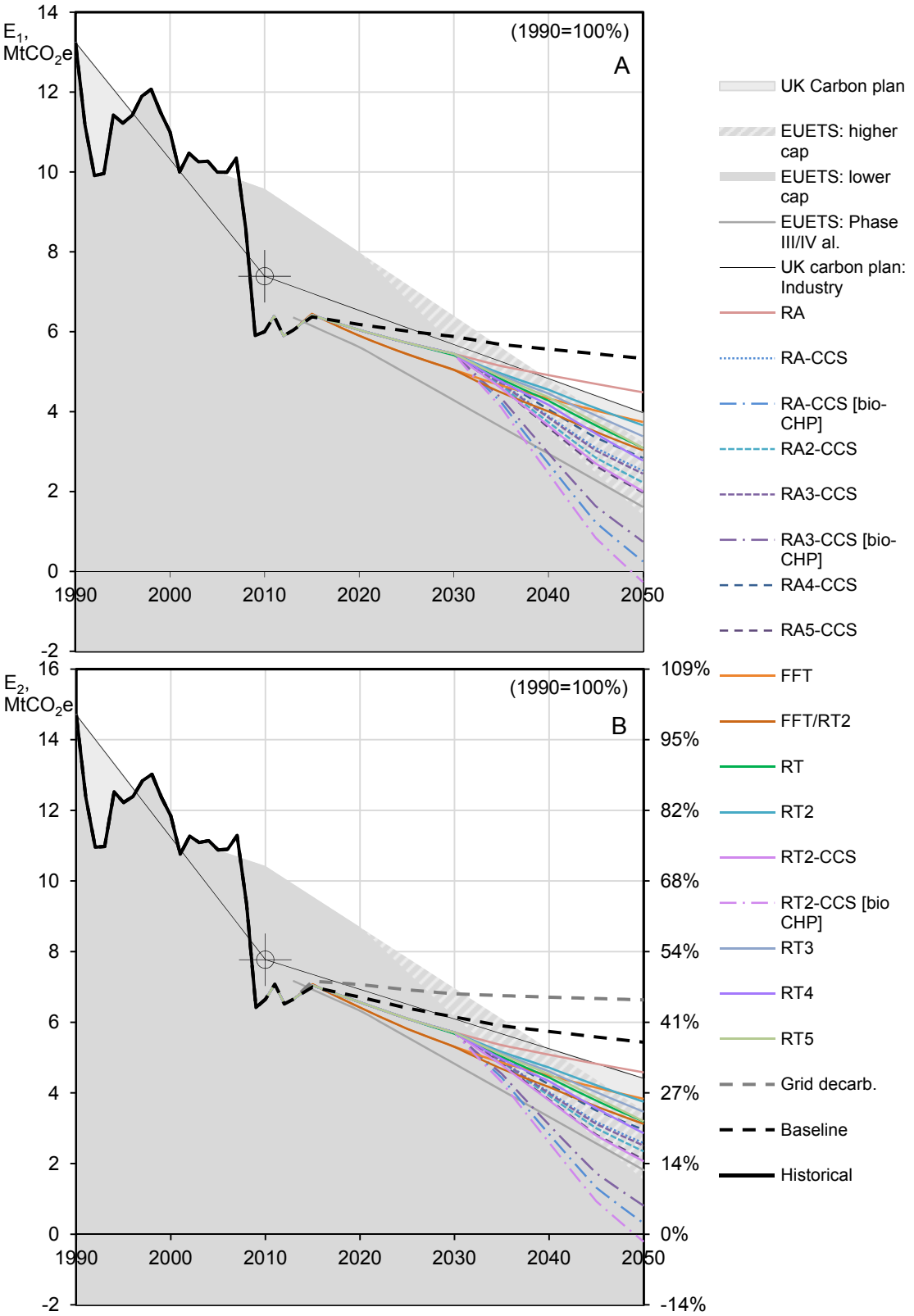

Figure 5-6: GhG emissions pathways of technology roadmaps for the UK cement sector

5.5 Discussion

GhG emission from the UK cement sector has halved over the 1990-2010 period. Noteworthy improvements in aggregate emissions intensity include a continued shift to dryer feedstock, capacity rationalisation, fuel switching, and clinker substitution. However, most of the sector's transformation is a result of its diminished size, caused by forces external to the industry. In particular, the recent recession contributed to the over allocation of about 4MtCO_2 per year of allowances during phase II of the EUETS (DECC 2007a, Environment Agency 2013). Because production is not expected to return to its pre-recession level, the sector has a large structural surplus of allowances. This could undermine the correct functioning of the carbon market for the sector.

There is technical potential for deep emissions reduction through alternative cements and CCS, though the cost and availability of these options is uncertain. Capture cost is likely to be high. In a detailed techno-economic study (IEAGHG 2008) abatement cost of post-combustion CCS was calculated at around 70£/tCO_2 with production cost doubling for a 1Mt/yr site from about 45£/tc to 85£/tc[30]. Alternatively, retrofit oxy-fuel combustion technology at the precalciner would cost 27£/tCO_2 and yield a 54£/tc production cost. However this technology is limited to capturing about 60% of plant emissions. Full plant oxy-fuel combustion represents a much greater technical challenge and cost, and is likely to be an option for new installations only (ECRA 2009b).

Irrespective of capture costs, the cost and availability of CO_2 transport and storage presents an even greater challenge. This is because most UK cement kilns have low capacity and the largest kilns reside outside industrial cluster regions identified for the deployment of CCS transport infrastructure (DECC 2012, Element Energy 2010a). At the same time, viable cement manufacture is dependent on proximity to chalk and limestone deposits as it is uneconomic to transport large tonnages of low cost raw material. These natural deposits also need to be sufficiently dry for modern kilns.

Cement kilns with clinker capacity below 1.4-1.8Mt/yr (4000-5000t/d) were considered unlikely for post-combustion CCS by the WBCSD/IEA roadmap due to their higher specific costs (IEA 2009a). Only the 1.5Mt/yr kiln in Rugby falls within this range. Figure 5-7 shows the location and relative emission of UK cement plants and other industrial emissions sources. Cluster regions identified for storage under the North Sea (Element Energy 2010a) and the Irish Sea (DECC 2012) are shown.

[30] Figures converted from 2008 euros to 2010 pound sterling with a currency rate of 0.694£/€ (used in the study) and annual cost index of 0.96 (derived from the Chemical Engineering Plant Cost Index - CEPCI).

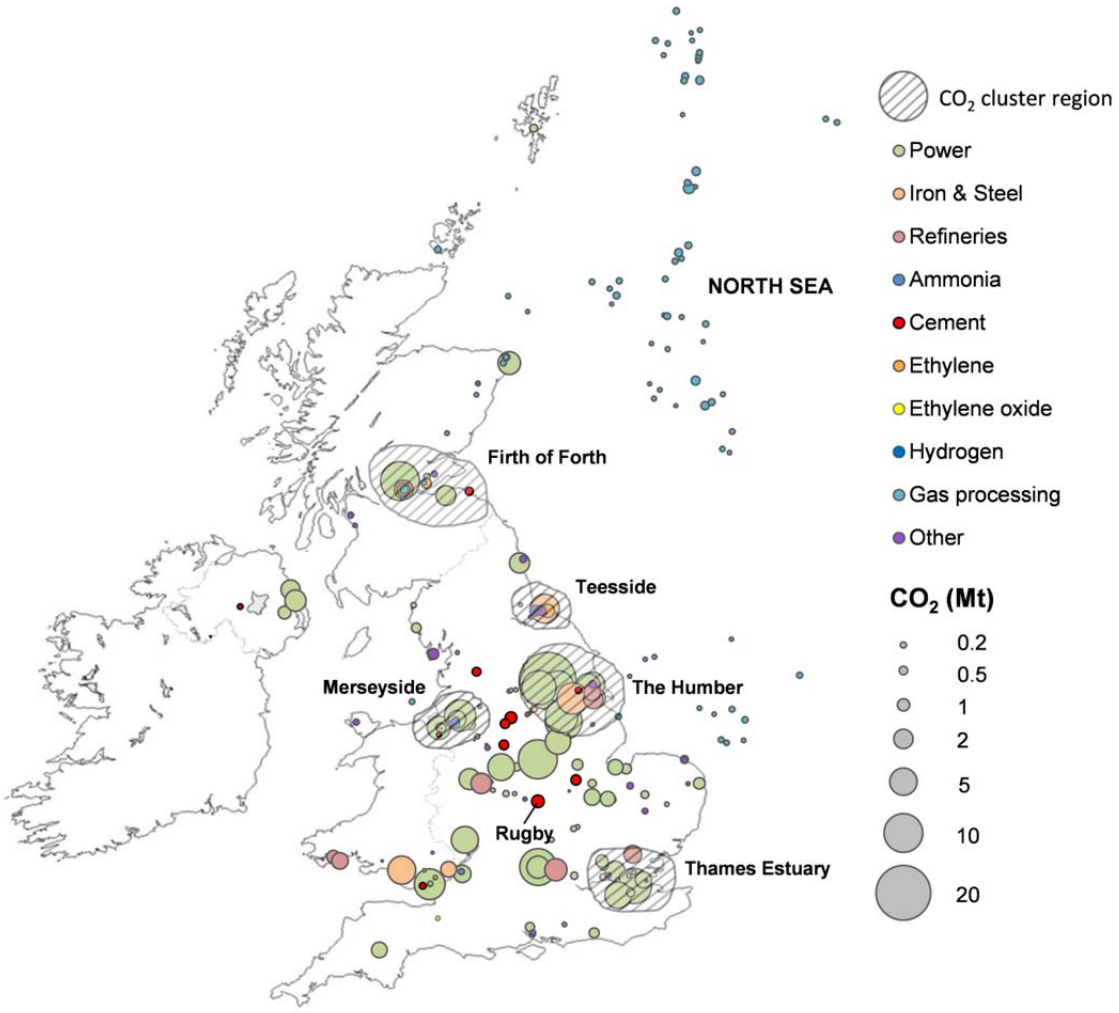

Figure 5-7: Distribution of CO_2 point sources in the UK, data collected over the period 2001-2003 from Needes (2012), cement sector updated with 2010 data from the Environment Agency (2013)

The large Rugby kiln is not only situated away from these regions, but is isolated from other emission points. Plants inside the cluster regions represent 20% of sector capacity and include Dunbar, Padeswood, and South Ferriby. Only the semi-dry plant at South Ferriby, by the Humber, has been indicated by the British Geological Survey (2014) as having a raw material reserve life of over 40 years. The sector will therefore need to relocate and further rationalise production, and expand quarrying activities, before there can be any reasonable opportunity for utilising CCS on a large scale.

The uptake of cement alternatives may also be considered speculative. OPC is a well-established product with mature supply chains. The construction industry is characteristically wary about unfamiliar products and Europe is more restricted by regulation than other markets such as China and Australia (Von Weizsäcker et al. 2009). Existing EU and US standards have essentially been shaped by Portland cement and concrete manufacturing bodies for over a century (Duxson and Provis 2008). They are prescriptive and do not recognise the mechanical properties or chemical paradigms of other cement systems. Despite various sources presenting alternative cements as the

optimal pathway, e.g. Croezen and Korteland (2010) and Von Weizsäcker et al. (2009), they appear a less serious pathway in the WBCSD/IEA and MPA roadmaps. It is evident that the Portland cement industry intends to thrive into the long-term with the aim supplying its well-tested, familiar product to the construction industry (Taylor, 2011).

Of the alternative cements identified, however, Aether is the least revolutionary and could gain quicker acceptance. The clinker is partially based on the same raw materials and can be produced in existing cement kilns. The research is funded by French company Lafarge, which is the largest OPC producer in the UK, and properties are being testing in collaboration with the UK-based 'Building Research Establishment' (Walenta 2013).

5.6 Summary and conclusions

A bottom-up energy and material database was exploited to examine past, present and future resource demands and GhG emissions of the UK cement sector. The sector structure, technological status, and resource demands were modelled to determine an energy and emissions baseline. Key technological opportunities available to the sector for abating emissions over the period to 2050 were identified. All options were modelled with the baseline into a detailed bottom-up technology roadmap projection model. Illustrative roadmaps were designed to map routes to various levels of emissions abatement by 2050.

The cement sector has contracted significantly from past recessions, which has diluted the challenge for meeting emission targets. Further emission reductions from efficiency and fuel switching are limited because these measures do not reduce process emissions, and because significant progress in these areas has already been made. Clinker substitution does avoid process emissions but its extent is limited effects on the material properties of OPC. Therefore, deep reductions will depend on CCS or radical process transition, or a combination of the two.

The main challenges facing CCS deployment in the sector are in reducing the cost of capture technology, e.g. via the commercialisation of oxyfuel combustion, and in gaining timely access to CO_2 transport and storage infrastructure. The main challenges facing the expansion of alternative cements in the sector are in the uncertainty of their development and the barriers imposed by prescriptive standards in the construction industry.

The projection model is flexible enough to incorporate any future scenario for the sector involving these options and was constructed to incorporate the economic information collected under the UED project. Thus, further assessment and minor modification of the model could yield a wide range of detailed techno-economic insights.

6 The chemicals sector

In this chapter a bottom-up study of energy demand and GhG emissions in the UK chemicals sector is made. Due to an evidently higher level of commercial confidentiality, energy and physical output data at the process level was unobtainable. Therefore the approach taken was to combine general efficiency data at the European level with estimations of UK production based on plant capacity data (ICIS 2013), or based on energy feedstock data published in energy and emissions statistics (DECC 2014b, ONS 2014b).

As with the other sector studies, most data was collected under the UED project of the UK Energy Research Centre. Coverage from the project of the chemicals sector is updated and elaborated on in this chapter. The sector covers SIC (07) groups 20 'Manufacture of chemicals and chemical products' and 21 'Manufacture of basic pharmaceutical products and pharmaceutical preparations'. The bottom-up approach requires that some refinery activities are also incorporated. The SIC (07) group 20.14 'Manufacture of other organic chemicals' encompasses petrochemicals production, and this production integrates with SIC (07) group 19.2 'Manufacture of refined petroleum products'.

As with the cement sector, this study is of limited detail when compared with the study conducted for iron and steel. There are two reasons for this. Firstly, from the bottom-up perspective the chemicals sector is not a single sector; rather, it a collection of sectors. Taking the most energy intensive process systems associated with chemicals, energy demand and GhG emissions amount to a fraction of that found in the iron and steel sector. Secondly, unavailability of present and historical UK data at the process level precludes the kind of detail applied for iron and steel. Despite these differences, the bottom-up approach outlined in section 2.5 is broadly adhered to. However, historical assessment is limited to the use of sector-level energy and emissions statistics, and the baseline model is less precise. Time limitations have also prevented the incorporation of economics in the sector's bottom-up roadmap projection model.

In section 6.1, the sector is introduced along with an overview and breakdown of existing structure. In section 6.2, an energy and emissions baseline for the sector is established. In section 6.3, a cursory examination of technical improvement potential is made. In section 6.4, technologies that could contribute to minimising resource demand and GhG emissions in the sector out to 2050 are identified and their representation for modelling is described. In section 6.5, a bottom-up technology roadmap projection model is introduced and 2050 roadmaps are constructed and assessed. In section 6.6, observations and insights deriving from the chapter's analyses are discussed. In section 6.7, the chapter is summarised and concluded.

6.1 Introduction

The chemicals industry has progressed through three phases of feedstock dependency (Langley 1984b): Coal, oil, oil and gas. During the first half of the 20th century the sector was largely based on coal via tars and other by-products of coke and coal gas production. From the mid-1950s the availability of petroleum products enabled a cheaper route to existing products from coal and opened up whole new markets, e.g. plastics. Oil provided for both fuel and feedstock, and the sector expanded at an average rate of 6% per annum during the 1960s and 1970s (Langley 1984b). From around 1970, natural gas began to displace some of the uses for oil and has increased in significance over time. However this transition was less dramatic than the first and there remains a large dependency on petroleum products in the sector.

With diminishing oil and gas reserves in the North Sea, and the expectation continuing constraints on GhG emissions, the next phase of feedstock dependency will involve biomass. Transitions to biotechnology is well covered in literature (IEA 2009c, Patel et al. 2006, Shen et al. 2009), and it is considered an area of research strength for the UK economy (CBI 2012).

Many manufacturing sites in the sector are large integrated complexes owned by one or several companies. The companies typically belong to major multinationals capable of transferring process technology and shifting production elsewhere in pursuit favourable conditions, such as cheaper energy and feedstock. European trade intensity in the key upstream subsectors of basic organic and inorganic chemicals is 58% and 47% respectively (European Commission 2014d). With most other chemicals subsectors having trade intensity of over 30%, nearly all the sector is classified by the European Commission as being at risk of carbon leakage (ibid.).

6.1.1 Sector structure

The chemicals sector has a heterogeneous structure. It is diverse collection of disparate processes manufacturing a wide range of intermediary and final chemical products. Many of these processes are linked within and between subsectors as part of a complex web of product and feedstock flows spanning beyond the geography of the UK. The sector also integrates with the petroleum refining industry via the production of petrochemicals such as ethylene, propylene, and benzene. Many processes use fossil fuel as both an energy source and as a feedstock, and may produce an array of co-products and by-products destined for sale, processing downstream, reprocessing upstream, or combusting in onsite electricity and heat generating plant.

Due to the sector's high demand for steam and electricity it has long been the largest owner of generating plant (Langley 1984b) and most autogeneration in the sector today is met by CHP (Judd, A., DECC, pers. corr., September 2013). About 40% of fuel combustion in the sector occurs at CHP plant and the sector exports significant amounts of heat and electricity. Some

large CHP installations are classified in the DUKES as major power producers (MPPs) and supply electricity predominately to the national grid (DECC 2014b).

In defining the sector boundary, division with MPP and petroleum refining sectors must be made clear. From a bottom-up, technological perspective there is no division with the refineries sector as far as petrochemicals production is concerned. As some technologies produce significant amounts of by-product fuel, a bottom-up view should also incorporate the consumption of such fuels for heat and power. This is especially the case for integrated sites and implicates MPP and non-MPP CHP plant of both the chemicals and petroleum refining sectors.

Overall the chemicals sector was modelled as producing about 13Mt of product (17Mt including petrochemical feedstock, e.g. naphtha and ethane) in 2010 at over 20 sites. A significant proportion of these products were feedstock for other products so the figures represent a gross production of manufactured materials. This is distinct from the steel and cement sectors, which were modelled as homogenous process systems each with a single system product.

The breakdown of sector structure is given below. The scope of this breakdown is the chemicals sector (SIC 20, 21) plus energy for petroleum feedstock production and CHP plant at integrated refineries.

- Petrochemical process
    - Steam cracking (of ethylene, propylene, etc.)
    - Petrochemical feedstock production (of naphtha, ethane, etc.)
- Other chemical process and miscellaneous
    - Identified chemical process (steam reforming, polymerisation, etc.)
    - Other (unidentified or ancillary processes, boiler plant, energy overheads, etc.)
- CHP and non-CHP power plant (including MPP)
    - Chemicals (includes one petrochemicals site and 'other generation')
    - Refineries (includes two integrated petrochemicals sites)

The processes that were modelled for improvement or replacement include the petrochemical processes and other identified chemical processes discussed later. Production of petrochemical feedstock occurs outside of the chemicals sector boundary as set by the DUKES. It derives from the distillation of crude oil in the petroleum refineries sector or processing of natural gas. These upstream processes produce a range of other fuel and feedstock products. The energy required to drive these processes per mass of product is allocated to the production of petrochemical feedstock for the chemicals sector. The combined energy demand for the production of petrochemical feedstock and product is the cumulative process energy and is an appropriate measure for comparing replacement technologies (Ren 2009).

CHP and power plant output for the petrochemicals sector was estimated by back-calculating from emissions verified under the EUETS for plant at the sites of Wilton, Grangemouth and Fawley. Under the EUETS Wilton is reported by the chemicals sector and the other two sites are reported by the refineries sector (Environment Agency 2013). This split is reflected in the breakdown. Of the heat and power generated that is not related to the identified sites (other generation) nearly all is accounted for by CHP (Judd, A., DECC, pers. corr., September 2013).

The 'other' element is the energy remaining in the sector after all identified processes, CHP and other power activities are deducted. It was not modelled for process improvement but represents a large proportion of energy demand for the chemicals sector as a whole. Crosscutting opportunities relating to boilers, electric motors, HVAC systems, and other areas likely to play a role were deemed to be outside the scope of analysis.

6.2 Sector baseline

Figure 6-1 shows the split of energy demand in the chemicals sector derived from DUKES and EA statistics. The utilisation of by-product fuels and other petroleum products, e.g. propane, butane, and petroleum coke, not included in the DUKES' 'final energy consumption' is shown. Also shown is fuel consumed for CHP heat and power. Net heat trade after losses is small so is excluded here.

Figure 6-2 shows the energy demanded over the period 1990-2012 split by energy type. Fuel demand includes that which was consumed for CHP heat generation. After a gradual reduction in the use of coal and fuel oil in the 1990s, and aside from the necessary use of process by-product fuels, sector fuel demand is predominantly of natural gas. There is therefore little opportunity for further substitution by cleaner fossil fuel. The electricity demand shown here is the simple primary energy equivalent of final demand, which includes energy requirement for total electricity demand. Energy demand for autogeneration is similarly dominated by natural gas.

As noted in section 3.1.1, the reporting of OPG in statistics includes an estimation of consumption of fuel-grade by-products at steam crackers (Webb et al. 2012). This fuel represents the part of petrochemical feedstock which is ultimately combusted in the sector and is relevant to steam cracking improvement potential. Figure 6-4 is a Sankey diagram tracing energy flows in the chemicals sector and includes demand for process cracker by-product fuel.

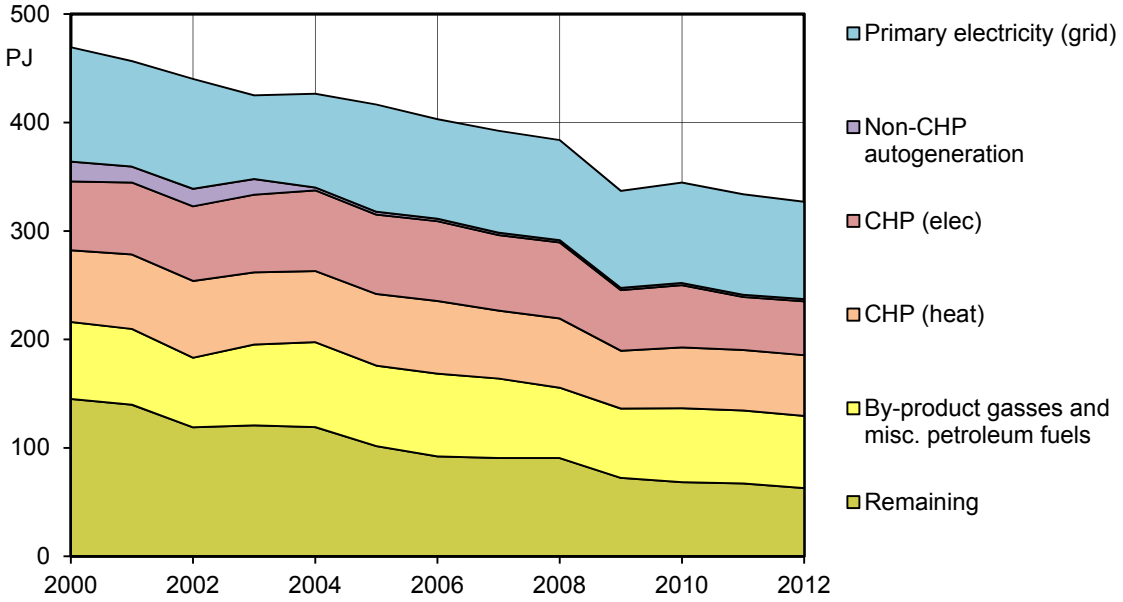

Figure 6-1: Energy demand split by process of the UK chemicals and sector and associated elements of the fuel industries (DECC 2013a, ONS 2014b)

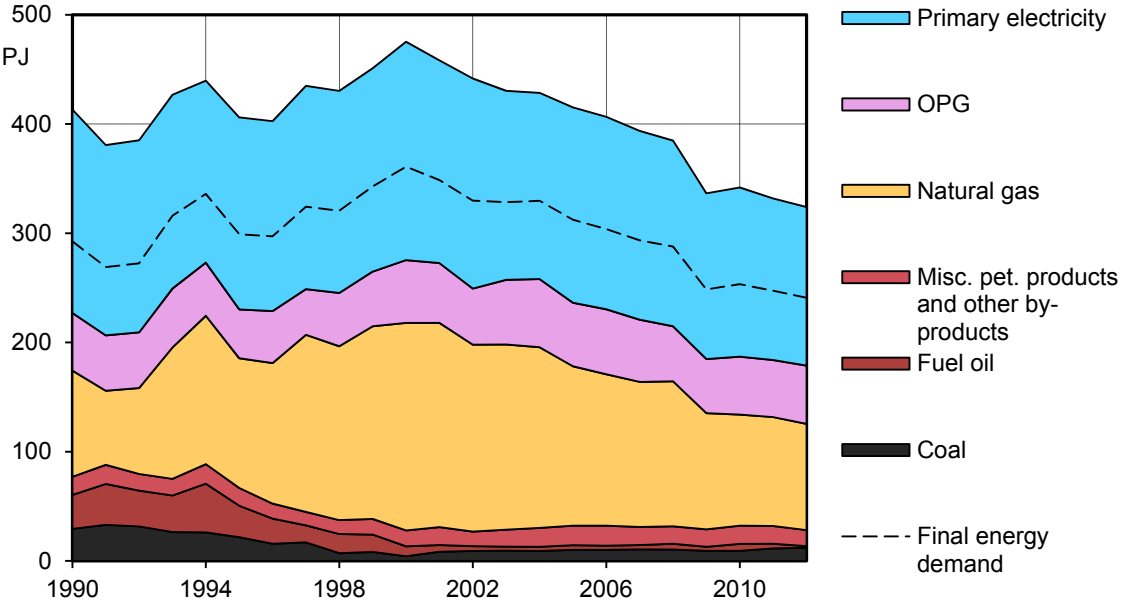

Figure 6-2: Energy demand split by energy of the of the UK chemicals sector (DECC 2013a, ONS 2014b)

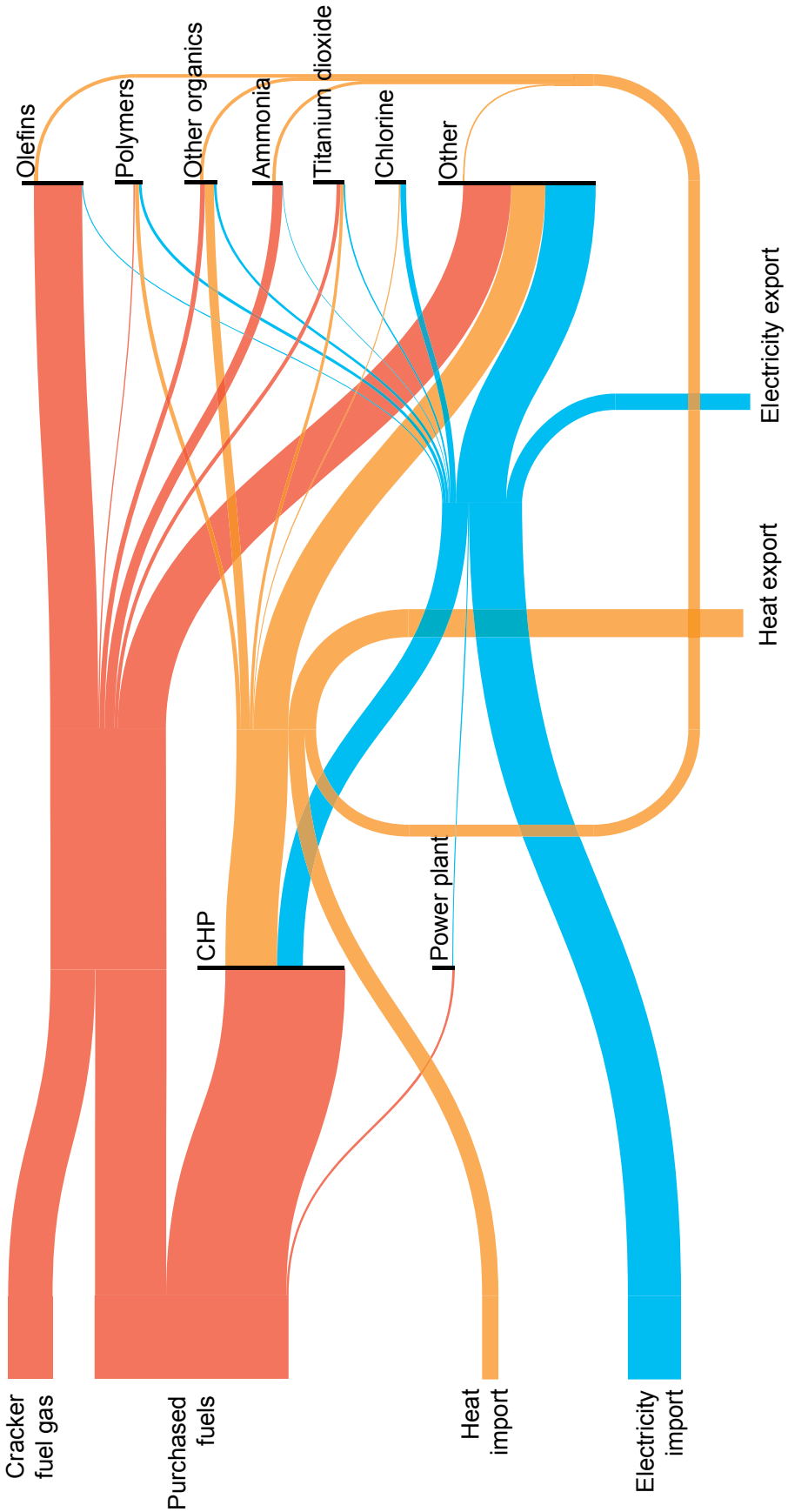

Figure 6-3: Sankey diagram and main energy flows in the UK chemicals sector in 2010

kg product per tonne feedstock	Feedstock						
	Naphtha	Gas oil	Ethane	Propane	Butane	Other[31]	Total
Share of total:	26%	3%	25%	22%	15%	8%	100%
High-value chemicals	645	569	842	638	635	645	688
Ethylene	324	250	803	465	441	324	489
Propylene	168	144	16	125	151	168	117
Butadiene	50	50	23	48	44	50	42
Aromatics	104	124	0	0	0	104	40
Fuel products/backflows	355	431	157	362	365	355	312
Hydrogen	11	8	60	15	14	11	24
Methane	139	114	61	267	204	139	157
Other C4 components	62	40	6	12	33	62	32
C5 and C6 components	40	21	26	63	108	40	51
C7 and non-aromatics	12	21	0	0	0	12	5
<430C	52	26	0	0	0	52	19
>430C	34	196	0	0	0	34	18
Losses	5	5	5	5	5	5	5
Process energy	264	261	314	249	242	264	270
Backflows to refineries	91	170	0	113	123	91	81

Table 6-1: Ultimate yields for steam crackers. Neelis et al. (2003)

6.2.1 Key processes

6.2.1.1 Steam cracking (lower olefins)

Based on the consumption of petrochemical feedstock published in the DUKES (DECC 2013a), it is possible to model the UK steam cracking process. The typical yield of products deriving from each feedstock along with proportion of feedstock consumed in 2010 is shown in Table 6-1. Total feedstock consumption was 4,069kt, equating to a production of 2,799kthvc.

Shown in Table 6-2 is data relating to the estimation of efficiency, energy and carbon dioxide emissions. Combustion emission is calculated from an estimation of process fuel demand. For simplicity, it is assumed that production of by-product fuel is equal to the approximate share, specified by Neelis et al. (2003), of process energy covered by feedstock. The remaining process energy is assumed to be met by natural gas. Fuel efficiency is 17.4GJ/thvc and is estimated by recalculating the European average of 16.9GJ/thvc (IEA 2009b) with the UK feedstock mix. The calculation of emissions from this method falls within 2% of the figure for verified emissions under the EUETS. This estimation was based 2008 data (see section 3.3.3).

[31] Assumed identical to naphtha based steam cracking

	Naphtha	Gas oil	Ethane	Propane	Butane	Other[32]	Total
SC fuel SEC, GJ/thvc	17.8	20.7	21	17.6	17.1	17.8	18.7
SC fuel SEC readjusted, GJ/thvc	16.5	19.2	19.5	16.3	15.9	16.5	17.4
SC fuel SEC readjusted, GJ/t ethylene	32.9	43.7	20.4	22.4	22.9	32.9	24.4
SC fuel, PJ	11.3	1.6	16.5	9.4	6.3	3.5	48.6
Share of SC fuel SEC from feedstock	100%	95%	80%	100%	100%	100%	-
By-product fuel CO_2 emissions factor, tCO_2/t	48.7	48.7	43.3	43.3	43.3	48.7	-
Supplementary fuel CO_2 emissions factor, tCO_2/t	-	50.5	50.5	-	-	-	-
Specific CO_2 emission, tCO_2/thvc	0.80	0.94	0.40	0.99	1.02	1.29	0.79
Specific CO_2 emission, tCO_2/t ethylene	1.60	2.13	0.42	1.36	1.47	2.57	1.11
CO_2 emission, $MtCO_2$	0.55	0.08	0.34	0.57	0.41	0.27	2.22

Table 6-2: Energy and emissions analysis for UK steam cracking, data for SEC, by-product share and by-product emissions factors from Neelis et al. (2003), readjusted SEC from IEA (2009b)

An estimation of average UK fuel SEC for BPT and BAT may also be calculated. By applying UK feedstock mix to the European BPT fuel SEC of 13.1GJ/thvc (IEA 2009b), BPT SEC becomes 13.5GJ/thvc. According to Worrell et al. (2008), BAT fuel SEC is 11GJ/thvc for naphtha steam cracking and 12.5GJ/thvc for ethane cracking. Assuming the average of these SECs for other feedstock flows, BAT SEC for the UK is 11.8GJ/thvc. This rudimentary assessment implies a technical improvement potential of 22-38%.

Figure 6-4 is a Sankey diagram depicting the calculated baseline energy flows for steam cracking. Shown in the diagram is endothermicity. Endothermicity is the theoretical amount of energy required in an endothermic reaction (Ren 2009). In this case endothermicity derives from the thermal energy released from the combustion of process fuel. The thermal energy enables the reaction converting feedstock to take place and the endothermicity remains in the calorific value of the product. The thermal energy delivered through the combustion of by-product fuel is thus energy which is released by and returned to the process feedstock.

[32] Assumed identical with naphtha based steam cracking

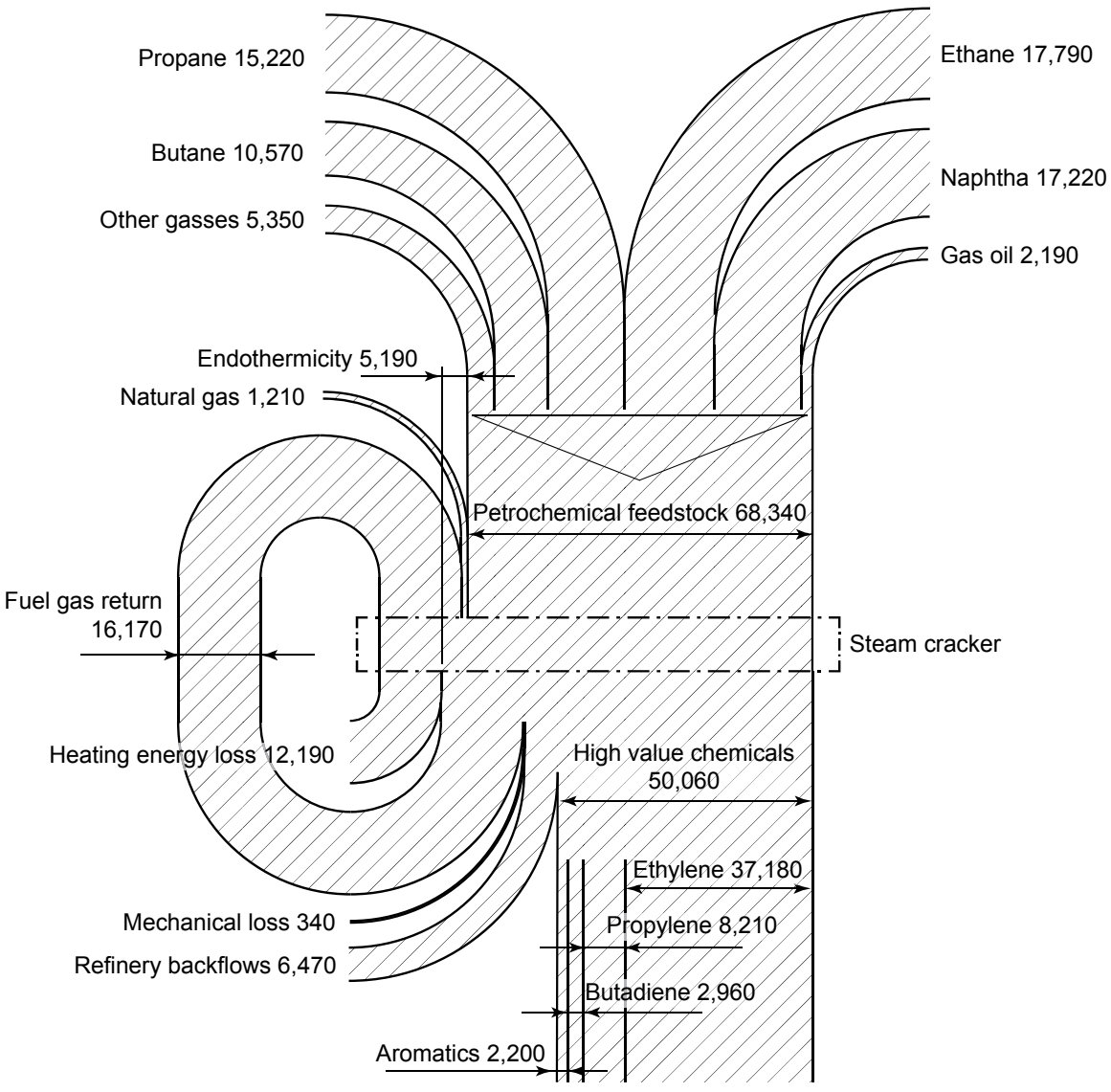

Figure 6-4: Sankey diagram of energy flows in the UK steam cracking process

In a techno-economic assessment of steam cracker technologies, Ren (2009) excludes endothermicity as part of process energy requirement. However, because the combustion of fuel releases GhGs, it may be considered more appropriate to include it. This is reflected by its recognition in a study by the IEA (2009c) in which Ren's technological assessment is summarised with endothermicity included.

6.2.1.2 Seam reforming (ammonia)

Most ammonia in the UK is manufactured by steam reforming with methane from natural gas. The steam methane reformer (SMR) separates methane into hydrogen and carbon dioxide. The hydrogen is put through a secondary reformer, the Haber process, in which it is combined with nitrogen from air to form ammonia. The hydrogen for ammonia production in the UK is manufactured at three sites: Ince, Billingham, and Saltend. Billingham and Ince use conventional routes while at Saltend natural gas is used as feedstock for acetic acid and acetic anhydride production, of which the hydrogen by-product is subsequently fed through a small adjacent ammonia plant (DECC 2007b).

Natural gas for feedstock and combustion in conventional steam reforming is estimated for the GHGI. For 2010 these were 17.1PJ and 9.1PJ respectively (ONS 2014b, Webb et al. 2012). Production related to this feedstock was 857kt, giving an overall fuel SEC of 30.5GJ/tNH_3. BAT fuel SEC of ammonia production is as low as 27.6GJ/tNH_3 and may be met by the conventional process route with heat exchange 'autothermal reforming' technology (European Commission 2007a). Based on this comparison, technical improvement potential for UK ammonia production is 10%.

6.2.2 Baseline summary

Table 6-3 is a breakdown summary of energy and emissions in the chemicals sector as it has been modelled. Fuel demand is shown with the estimated consumption of steam cracker by-product gas as this is included in the calculation of GhG emission. Consumption of cracker by-product gas was estimated for the GHGI and allocated to OPG consumption (Webb et al. 2012). This estimation is superseded here by the calculation in the previous section. Sector OPG demand is that reported for use in CHP and production of petrochemical feedstock only. To view the bridge between energy statistics and the chemicals baseline, refer to section A7.1 of the Appendix.

Sector division	Absolute energy, PJ					Absolute GhG emission, $MtCO_2e$			
	Fuel (inc. SC by-prod.)	Steam	Elec.	Direct energy	Primary energy	Comb. emission	Process emission	Scope 1 emission	Scope 1-2/3 emission
Sector	239 (284)	-23	27	243 (288)	302 (348)	16.3	2.7	19.1	21.6
Sector, exc. upstream	194 (239)	-13	38	219 (265)	297 (342)	13.8	2.7	16.5	21.3
Sector, modelled	33 (78)	12	19	63 (109)	97 (142)	3.9	2.6	6.5	9.9
Steam cracking	3 (49)	-4	1	1 (46)	2 (47)	2.2	0.0	2.2	2.2
SC feedstock prod.	10	0	0	10	10	0.6	0.0	0.6	0.6
Ammonia prod.	9	-3	1	6	7	0.5	1.0	1.5	1.4
Other chemical process	10	19	17	46	77	0.6	1.6	2.2	5.8
Heat and power	150	-64	-39	47	-	8.9	0.0	8.9	-0.7
Refineries	34	-10	-11	13	-	2.0	0.0	2.0	-0.2
Chemicals	116	-54	-28	34	-	6.9	0.0	6.9	-0.4
Other	56	29	48	132	206	3.5	0.1	3.7	12.3

Table 6-3: Energy and GhG emissions baseline summary of the UK chemicals sector

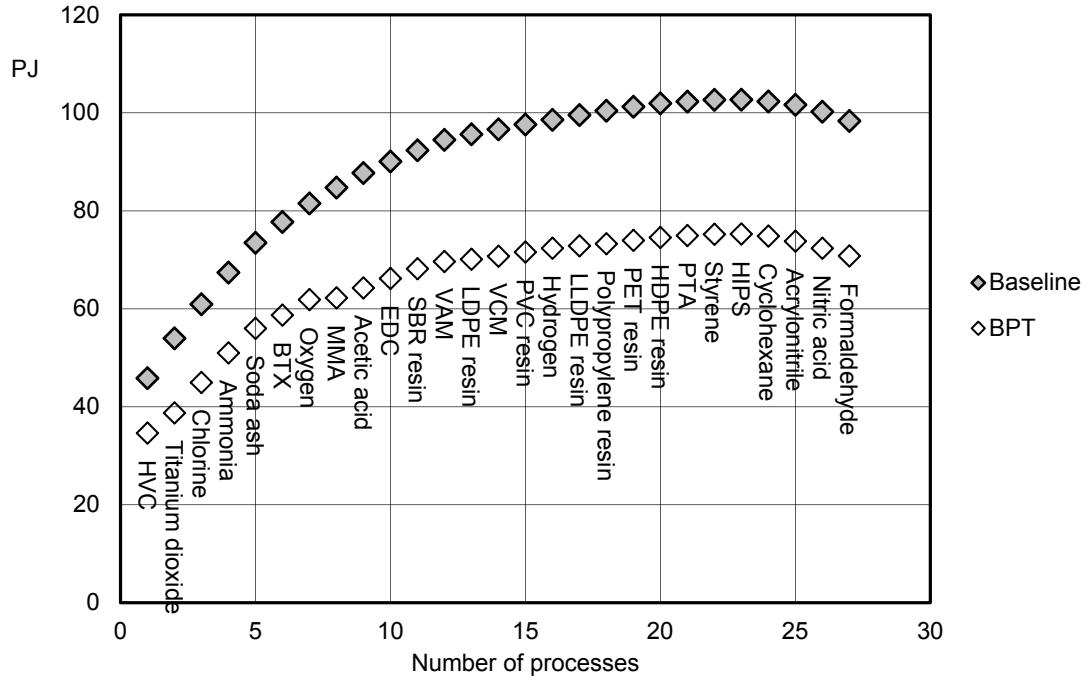

Figure 6-5: Direct net energy demand (fuel, steam, and electricity) of the baseline and BPT level for chemical processes in the UK

6.3 Technical improvement potential

In a report for the IEA (2009b), a broad technological improvement potential assessment was conducted for the global chemicals and petrochemicals sector. The study analysed improvement potential offered by the application of best practice technology (BPT) to a portfolio of 66 of the most common processes. As defined in the study, and in section 4.3.2, BPT is the best technology currently in use and therefore economically viable. This is distinct from BAT which can also include proven technologies that are not yet economically viable.

Although the IEA report had a global remit, most of the BPT and average SEC data sourced was European based, and thus provides a reasonable representation for the UK. By taking the SEC data and applying it to UK process outputs it was possible to build a simple bottom-up estimation of process energy demand and emissions in the sector. Production from most processes was estimated by collecting plant capacity data from published sources, e.g. ICIS (2013), and applying estimated load factors. Weighted average load factor for the sector in 2010 was estimated at 75%. Exceptions to this method are for the production of lower olefins and ammonia (section 6.2.1). For detail on the production estimations refer to section A7.1 of the Appendix.

Figure 6-5 shows the energy demand accumulated from 27 identified processes in the UK chemicals sector. It can be observed that production of high value chemicals from steam cracking demands by far the greatest amount of energy. The curve then rises steeply for titanium dioxide, chlorine, soda-ash, and ammonia before reducing in gradient. The curve peaks before the last process as some processes are exothermic and net energy producers. Altogether, BPT has the

potential to reduce direct energy demand from 98PJ to 71PJ, or save 28PJ (28%). Using the sector efficiency of steam generation (95%) and weighted average efficiency of owned and imported electricity, simple primary energy reduction is from 121PJ to 88PJ, or a saving of 33PJ (27%). Given the dominance of lower olefin production, applying the BAT standard for steam cracking provides a reasonable approximation for sector BAT potential. Improvement potential of direct and primary energy becomes 41PJ and 36PJ respectively, or just over a third. The associated reduction in GhG emissions from BPT and BAT is 1.8MtCO_2e (22%) and 2.3MtCO_2e (27%) respectively.

Due to the potential for error in the use of European efficiencies and the estimation of load factors, the improvement potentials calculated here should be treated as indicative.

6.4 Technological identification and representation

Identified technologies and measures are described here for each of the key processes analysed for the baseline. The technologies were chosen on the basis that they may feature in the UK chemicals sector in the time to 2050.

6.4.1 Petrochemicals production

The technologies assessed here represent options for either substituting existing facilities with radically different process routes, or maintaining existing facilities and retrofitting carbon capture equipment. The representation of alternative processes was largely informed from an assessment by Ren (2009), while the application of CCS was mainly informed from analysis by Johansson et al. (2012). Both of these studies provide detailed techno-economic comparison within a wide portfolio of options. Many of these options were modelled with ancillary heat and power systems to meet new demand. These systems are treated as additional to existing onsite heat and power capacity in the sector, which are kept separate to avoid risk of double counting opportunities in the energy sector. However, the model allows downsizing of existing facilities to compensate for new generating capacity or, in the case of alternative processes, the option to exclude the additional generation capacity. Moreover, for each option employing capture equipment there is choice as to whether the ancillary system is targeted for capture along with the petrochemical process. Although these features add flexibility to the model, it is not possible to accurately integrate new and existing systems without more detailed and reliable data on the energy balances of individual petrochemicals sites.

It is noted that this assessment excludes the processes for manufacturing alternative plastics, such as starch plastics and poly-lactic acid (PLA), that could partially replace conventional plastics applications and therefore petrochemical steam cracking. This exclusion is due to a lack of available technical and economic information.

6.4.1.1 Waste plastics utilisation

It is possible to convert waste plastics, such as the polypropylene in plastic carrier bags, into naphtha and other oils. The method uses hydrogen, steam and other catalysts to produce the petrochemical feedstock through a stepped process of liquefaction, pyrolysis and separation. Originally developed by BASF in Germany, the technology was abandoned before reaching commercial scale (Ren 2009).

According to an estimation by WRAP (2006), plastic waste arisings in the UK were about 3Mt in 2010. Of this, around 2Mt is packaging waste which is not collected for recycling. However, not all of this would be available as feedstock and the economics of the process and feedstock together, relative to oil prices, would dictate the level of substitution. The model enables any substitution rate, though a diversion of 10% of the available waste stream (200kt) is assumed. Naphtha consumption for steam cracking in 2010 was about 1Mt so this equates to a substitution rate of 20%.

6.4.1.2 Naphtha routes

Naphtha can be produced from methane (natural gas), coal or biomass in various processes including the Fischer-Tropsch (FT) process. FT naphtha is converted from methane via natural 'gas-to-liquids' processes or from coal via 'indirect liquefaction' (Ren 2009). Biomass is similarly converted to FT naphtha via FT processes though efficiency is influenced by high moisture contents. Steam cracking with FT naphtha typically produces a 40% higher ethylene yield than conventional naphtha though, owing to an absence of aromatics, produces only a 5% higher HVC yield. Coal and lignocellulosic biomass may also be processed together for added flexibility. Lastly, coal may instead be used in the process of 'direct liquefaction' but produces aromatic-rich naphtha with a 15% lower HVC yield (ibid.).

All routes have yet to reach commercialisation except the methane route, which has been deployed in South Africa by Mossgas and Malaysia by Shell (Ren 2009). Nevertheless, the biomass and biomass/coal blend options via FT processes were modelled as these present the greatest reduction in GhG emission from the present baseline.

6.4.1.3 Methanol routes

Methanol provides an alternative route for converting methane, coal or biomass to olefins. The methanol-to-olefins (MTO) route comprises of three steps: methanol production, methanol conversion to olefins and gasoline, and product recovery and separation (Ren 2009). Methanol is produced from methane, coal and biomass by gasification at elevated temperatures into a syngas, and subsequently converted to methanol via synthesis processes. Heat from methanol synthesis may be utilised to convert some of the methanol into dimethyl-ether and water, the former being used in the synthesis of olefins using a fluidised or fixed bed reactor. Recovery, separation and

cooling processes are essentially unchanged from those used for steam cracking, with the exact yield depending on the severity, catalysts used, and reactor configuration (Ren 2009). Research into MTO techniques began 20-30 years ago and two pilot plants currently operate in Norway (ibid.).

The MTO process is modelled via biomass gasification, and via coal gasification installed with CCS capture equipment.

6.4.1.4 Oxidative coupling

Oxidative coupling is a process by which ethylene can be converted directly from methane without the intermediate steps of methanol, naphtha, or ethane production. Oxidative coupling of methane (OCM) is also referred to as catalytic oxidative dimerization of methane or partial oxidation of methane to ethylene. For further background on the chemistry of the process refer to Swanenberg (1998).

A fluidised bed reactor is a common reactor design for the process. Oxygen reacts with methane inside the reactor in the presence of a catalyst to form a methyl radical (CH_3) and water (Ren 2009). By combining together, the methyl radicals form ethane which subsequently dehydrogenates into ethylene. The catalysts used were originally oxides of alkali, alkaline earth materials or other precious earth metals, and are desired in part to control the oxygen-ions to maintain the reaction (ibid.). However, novel catalysts based on research into genetically modified bacteriophages developed at MIT are presently being advanced by San Francisco based start-up Siluria (Bullis 2014).

One concern with the process is the difficulty in preventing the reaction from progressing and converting ethylene into carbon dioxide and water. Nevertheless, the recent breakthrough in catalyst has yielded promising results in two pilot plants built in 2012, and a larger scale demonstration plant is to begin operation by 2015. The company has also partnered with German cracker equipment supplier Linde, to scale up the plant for commercialisation within the next few years (Tullo 2014).

The reaction takes place at two thirds the temperature of steam cracking and is exothermic. The energy generated by the reaction is also sufficient to drive the process (Tullo 2014). However, efficiency of both fuel and feedstock requirement per tonne of ethylene has been analysed by Siluria to give a similar performance to ethane crackers (ibid.). Nonetheless, the process has a significantly lower capital cost. The process also has the potential for zero combustion emissions depending on the level of waste heat utilised and whether oxygen produced for the process uses a decarbonised electricity supply.

Due to the unavailability of more recent data, the technology used for the model is the 'OCM I' design developed by Ren (2009) and based on the work of Swanenberg (1998).

6.4.1.5 Ethanol routes

It is possible to convert biomass into ethanol for subsequent dehydration forming ethylene. There are three well-known methods for producing ethanol from renewable sources (Ren 2009): direct fermentation of starch/sugar rich biomass, e.g. maize starch, sugar beet, sugar cane; hydrolysis of lignocellulosic biomass, e.g. wheat, wood, agricultural waste, and subsequent fermentation to ethanol; and lignocellulosic biomass gasification with microbial fermentation or chemical conversion with a catalyst.

Detailed analysis on bioethanol production processes as part of a portfolio of white bio-technology opportunities was undertaken by Patel et al. (2006) under the BREW[33] project. Ethanol production via lignocellulosic biomass is still in the development stage and has yet to have been demonstrated at an industrial scale. The production of bioethanol from sugar and maize already exists in production facilities worldwide, and a 0.2Mt/yr ethanol-to-ethylene (ETE) production plant based on sugarcane began operation in Brazil in 2010 (Braskem 2010). Installed and planned annual bioethanol capacity in the UK is nearly 1Mt with 90% derived from wheat versus 7% from sugar beet and 3% from municipal solid waste (Alberici and Toop 2013). The UK does not presently have ETE capacity.

The UK predominantly manufactures bioethanol from wheat but also utilises sugar beet. The feedstock reported in the in the literature consulted for the present work was maize and sugarcane (Patel et al. 2006, Ren 2009). As choice of feedstock can influence energy and emissions intensity (Muñoz et al. 2013), these representations should be treated as indicative for the UK. ETE based on ethanol from starch, sugar, and lignocellulosic biomass was modelled. In the case of lignocellulosic biomass, the option of utilising more of the resource in CHP is provided.

6.4.1.6 Retrofit CCS

Post-combustion CCS technology may be used for targeting CO_2 in the flue gas of the cracker furnace. In a techno-economic study by Johansson (2012), the use of standard MEA solvent absorption technology with 85% capture efficiency was assessed. To meet the additional steam demand a range of heat supply configurations was modelled. These include the use of a NGCC CHP, a natural gas boiler, a biomass boiler, and process waste heat. The first three of these configurations were incorporated into the projection model. The option of capturing emissions from the ancillary plant is also provided. The use of process waste heat was not modelled as data on the present use of waste heat at UK crackers could not be obtained.

[33] Biotechnological production of bulk chemicals from renewable resources

6.4.2 Ammonia production

Given that separation of CO_2 is already an integral part of the steam reforming process, it is an economically attractive target for CCS and would not require additional separation equipment (Element Energy 2010b). The process emission accounts for some two thirds of total emissions and capture efficiency may be nearly 100% (Zep 2013). In some cases it is not possible to capture process CO_2 as it is used in the synthesis of urea and released during the product's application (ibid.). The UK, however, produces ammonium nitrate fertiliser and is therefore eligible for CCS. Capture of the 1MtCO_2 process emission from the steam reformers at Billingham and Ince was modelled for the projection assessment. A capture efficiency of 99% is assumed.

6.4.3 Heat and power plant

6.4.3.1 Fuel switching

Fuel switching to biomass at all identified generating plant is provided. The model separates a proportion of generating plant allocated to petrochemical production. Based on three sites this is estimated to account for a quarter of sector heat and power generation and 30% of associated emissions. The higher proportion of emissions is owed to the necessary use of refinery by-product gasses. This sets a limit on the degree to which fuel may be switched to biomass. As steam crackers improve in efficiency it is assumed that additional surplus cracker fuel gas is made available to CHP plant, lowering the limit for switching. This particular conflict is avoided by switching to alternative petrochemical processes, though upstream refinery gasses are assumed unchanged as the refinery may continue to produce these gasses regardless.

Fuel switching is also an option for the remaining generating plant but is far less restricted. In general, the biomass switch applies to coal and natural gas only. Coal is automatically prioritised for biomass substitution before natural gas.

6.4.3.2 Retrofit CCS

The option of applying CCS at all identified generating plant is provided. It is assumed that the application of CCS would have a 20% energy penalty and a direct capture efficiency of 85%. The energy penalty and capture efficiency are informed from literature (IEA 2011, Metz et al. 2005) and are applied conservatively here owing to the mix of fuels present. The model enables control of these variables.

Reflecting the application if CCS at steam crackers, CCS is assumed to be applied at the generation capacity representing petrochemical production. It was not possible to make an informed estimate as to the level of CCS at generation plant in the wider sector, so no deployment is assumed here.

6.4.4 Summary

Figure 6-6 summarises an energy and emissions assessment comparing the UK base steam cracker with replacement options[34] modelled by Ren (2009). Many of the process routes combine with electricity generation and the resulting displacement of existing electricity generation is incorporated. As modelled in the literature, generation efficiency is 55%. The bars in graphs B and C include the deduction of energy and emissions that would result from this generation displacing that from an NGCC power plant of the same efficiency. The error bars indicate the effect of displacing the present UK power supply system instead. In the time to 2050, decarbonisation of the UK grid would narrow and eventually reverse the error bars in Graph C. An average of 3.5MtCO_2e per tonne is assumed for product combustion (ibid.).

Only the technologies that result in a reduction in GhG emission are considered suitable for roadmapping. This includes OCM, CCS and biomass-based technologies. Partial biomass use, as in the case of the coal lingo FT naphtha SC is unsuitable. The technologies of lingo MTO, maize starch ETE, and waste naphtha are only suitable on the basis that the product would ultimately be combusted. Biomass derived products are assumed to have zero emissions at this stage as the combustion emission is of carbon recently absorbed from the atmosphere. In the waste-based naphtha route, it is presumed that the plastic waste would otherwise have been incinerated without energy recovery. In which case, emissions here are also cancelled.

Figure 6-7 is a comparison of retrofit CCS options for existing steam crackers. It can be seen that these options generally perform well compared with the alternative process routes. Abatement from CCS is more comparable with biomass based process routes if carbon in the product is not released at a later stage. On the other hand, these options are more resource efficient and rely on established supply systems.

[34] Roman numerals indicate variations on the size of autogeneration capacity and, in the case of OCM, a variation on process set-up and by-product energy use. MTP = Methane-to-propylene.

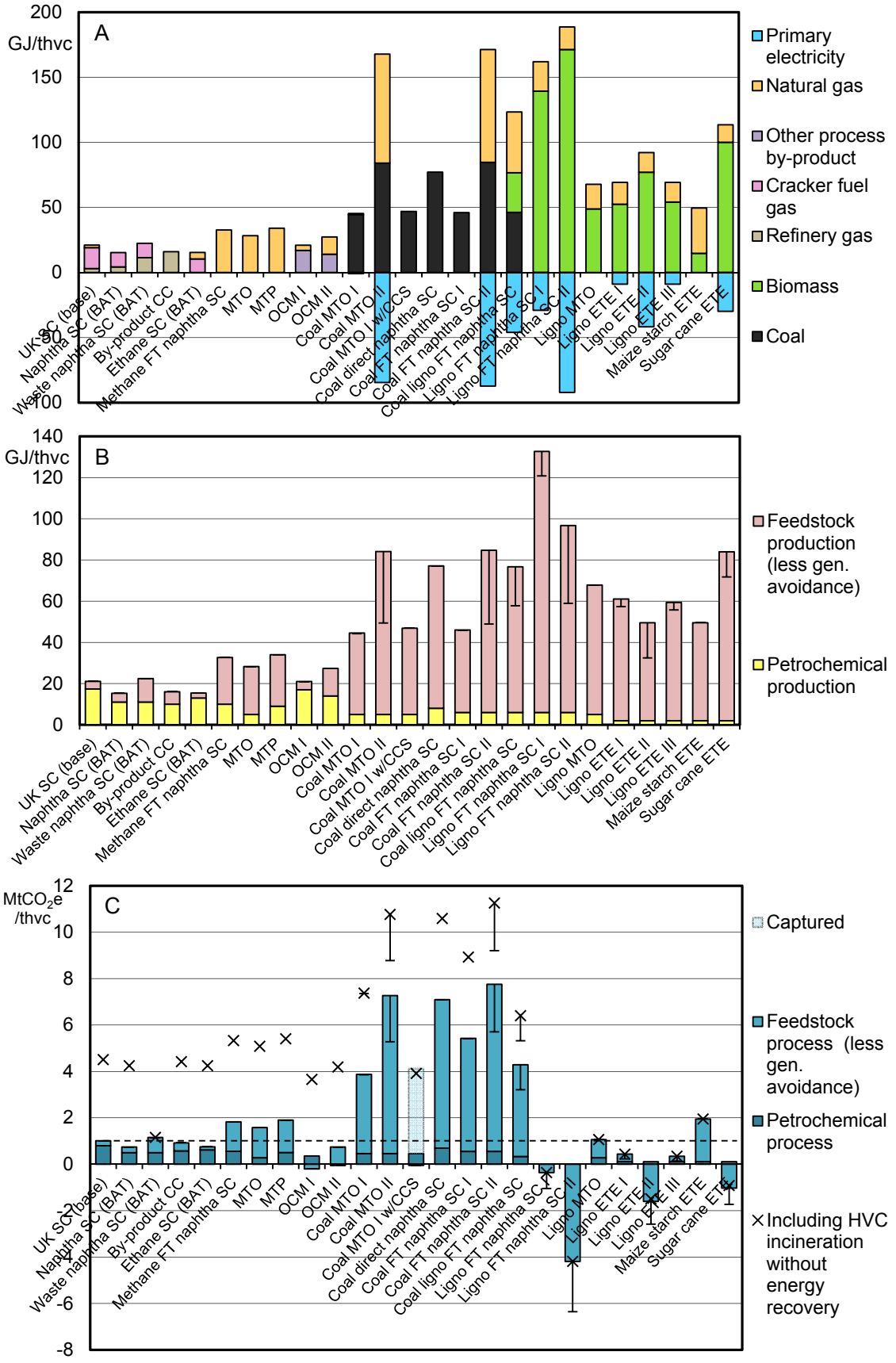

Figure 6-6: Petrochemical process route energy and emissions summary. Graph A: SECp by energy type. Graph B: SEC by process, less energy avoided from autogeneration. Graph C: SE2, excluding emissions avoided from autogeneration. Error bars indicating range of avoidance. Based on Ren (2009).

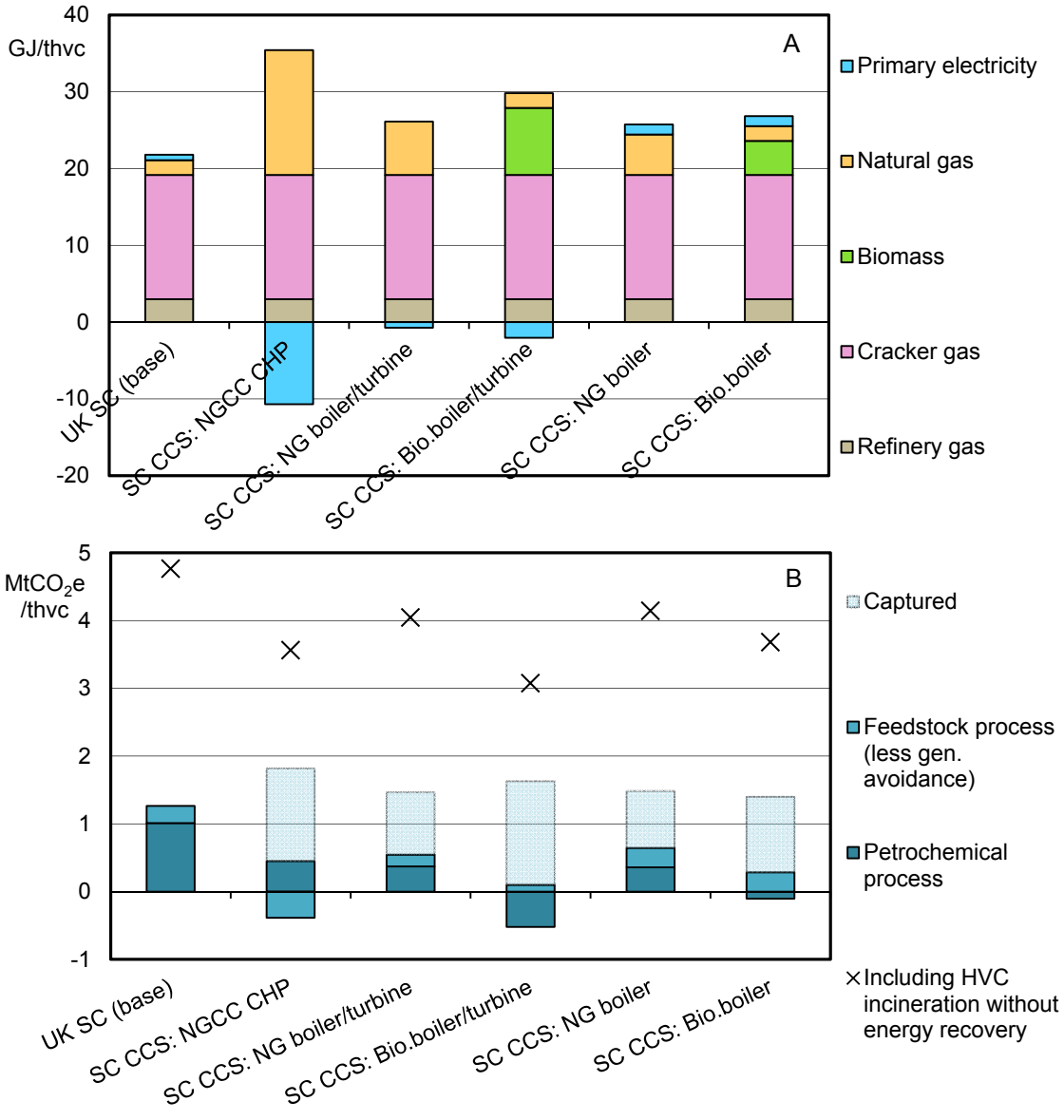

Figure 6-7: Petrochemical steam cracker retrofit CCS energy and emissions summary. Graph A: SECp by energy type. Graph B: SE2, less emissions avoided from autogeneration.

6.5 Technology roadmap assessment

In this section a technology roadmap assessment is conducted for the potential deployment of identified technologies out to 2050. The extent of resource demand and GhG emissions reduction is therefore quantified and investigated. A bottom-up technology roadmap projection model was built to conduct the assessment. For further detail refer to section A7.3 of the Appendix. Supplementary model outputs may be referred to in section A7.3.1 of the Appendix.

6.5.1 Baseline projections

The projected baseline is affected by sector output, grid decarbonisation, and deployment of BPT/BAT. It is assumed that the grid will decarbonise by 85% over the period 2010-2050 (see analysis in section A4 of the Appendix).

Owing to the high trade intensity of the sector and high dependency on fuel prices, it is impossible to suppose with reasonable confidence the future trend in petrochemicals production. Investment is going into UK shale gas extraction for use at Grangemouth (Ineos 2014). However the extent to which shale gas will affect the market over the short-medium-term is uncertain. Based on planned capacity closure and 2010 load factor, lower olefin production would be an estimated 2.4Mthvc in 2015. For simplicity, and in the absence of more detailed information, production level is assumed to remain at this level into the future. For the same reasons, production from other processes modelled in the sector is assumed to remain at the level in 2010.

It is assumed that baseline progress towards BAT will be gradual and reach the 2010 BPT level by 2050. Reductions in steam and electricity demand are assumed not to lead to reduced generation of heat and power in the sector but increased exports to the public distribution system. Efficiency improvements to CHP plant were not assessed here due to uncertainty from the impact of fuel switching. General efficiency improvements such as improved motors, boiler efficiency, etc, are assumed to steadily reduce the part of the sector not modelled for processes by 10% in 2050. This reduction is equal across fuel, steam, and electricity demand.

6.5.2 Roadmaps

Numerous illustrative technology roadmaps to 2050 are described in Table 6-4 and shown alongside GhG emissions accumulated over the years 2011-2050. For more detailed figures on technology uptakes for each roadmap refer to section A7.3 of the Appendix.

Biomass demand is also shown in Table 6-4 and highlights the greater levels necessary for the highest abating RT roadmaps. RT3 gives a similar abatement to RT5 but requires much larger amounts of biomass. RT5 [bio-CHP] would be a far more effective way to utilise this level of consumption.

	Energy efficiency	CHP fuel switching	CCS	Alternative feedstock/process for HVC production	E_1, $MtCO_2e$	E_2, $MtCO_2e$	E_{2fd}, $MtCO_2e$	E_2, $MtCO_2e$ (credit basis)	E_{2fd}, $MtCO_2e$ (credit basis)	Biomass fuel, EJ (Average yearly PJ) [of total]	Biomass feedstock, EJ (Average yearly PJ) [of total]	Biomass total, EJ (Average yearly PJ) [of total]
Baseline	Logistic curve improvement to BPT	Remaining coal (10%) to natural gas; 10% biomass	-	-	622	592	929	676	1014	0.16 (4) [2%]	-	0.16 (4) [1%]
RA	Logistic curve improvement to BAT	Remaining coal (10%) to natural gas; 20% biomass	-	-	605	581	918	659	996	0.31 (8) [3%]	-	0.31 (8) [2%]
RA [bio-CHP]		Remaining coal (10%) to natural gas; 80% biomass	-	-	559	557	895	613	950	1.09 (27) [12%]	-	1.09 (27) [7%]
RA-CCS		Remaining coal (10%) to natural gas; 20% biomass	100% MEA post-combustion SC with NGCC CHP; SMR CCS; petro-chem CHP CCS	-	547	551	888	593	931	0.32 (8) [3%]	-	0.32 (8) [2%]
RA-CCS2			100% MEA post-combustion SC with NG boiler and back-pressure turbine; SMR CCS; petro-chem CHP CCS	-	545	551	889	597	934	0.32 (8) [3%]	-	0.32 (8) [2%]
RA-CCS3			100% MEA post-combustion SC with biomass boiler/back-pressure turbine; SMR CCS; petro-chem CHP CCS	-	517	531	868	568	905	0.59 (15) [6%]	-	0.59 (15) [4%]
RA-CCS4			100% MEA post-combustion to SC with biomass boiler; SMR CCS; petro-chem CHP CCS	-	544	552	889	597	935	0.32 (8) [3%]	-	0.32 (8) [2%]
RA-CCS3 [bio-CHP]		Remaining coal (10%) to natural gas; 80% biomass	100% MEA post-combustion SC with biomass boiler and back-pressure turbine; SMR CCS; petro-chem CHP CCS	-	467	507	844	518	855	1.38 (35) [14%]	-	1.38 (35) [8%]
RA-CCS3 [waste naphtha]		Remaining coal (10%) to natural gas; 20% biomass		20% substitution of naphtha with waste derived naphtha in existing SC	521	534	863	572	901	0.59 (15) [6%]	-	0.59 (15) [4%]
RT			-	67% OCM	588	572	909	645	982	0.32 (8) [4%]	-	0.32 (8) [2%]
RT2			-	67% ligno MTO	617	589	848	671	930	1.42 (36) [13%]	1.55 (39) [22%]	2.97 (74) [17%]
RT3			-	67% ligno FT naphtha with biomass autogeneration	593	566	824	648	906	3.3 (83) [26%]	0.89 (22) [14%]	4.19 (105) [22%]
RT4			-	67% starch ETE	638	611	865	693	947	0.67 (17) [6%]	1.15 (29) [18%]	1.83 (46) [11%]
RT5			-	67% sugar cane ETE with biomass autogeneration	595	567	822	649	904	2.27 (57) [20%]	1.15 (29) [18%]	3.42 (85) [19%]
RT5 [bio-CHP]		Remaining coal (10%) to natural gas; 80% biomass	-	67% ligno ETE with biomass autogeneration	547	547	801	601	856	3.08 (77) [27%]	1.15 (29) [18%]	4.23 (106) [24%]

Table 6-4: Descriptions and abatements of technology roadmaps of the UK chemicals sector (2010-2050; figures are cumulative over years 2011-2050)

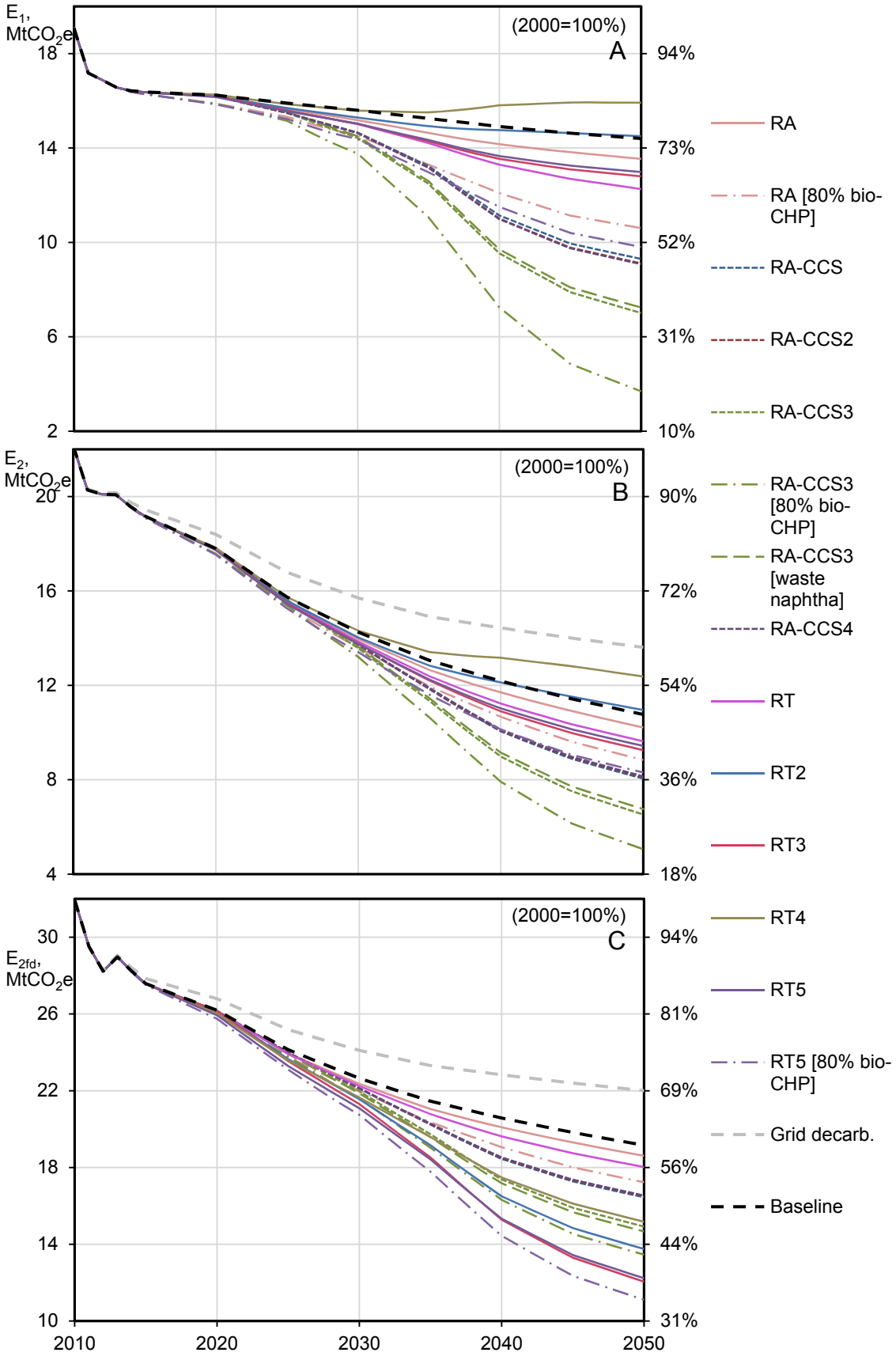

Figure 6-8: GhG emission pathways of technology roadmaps for the UK chemicals sector

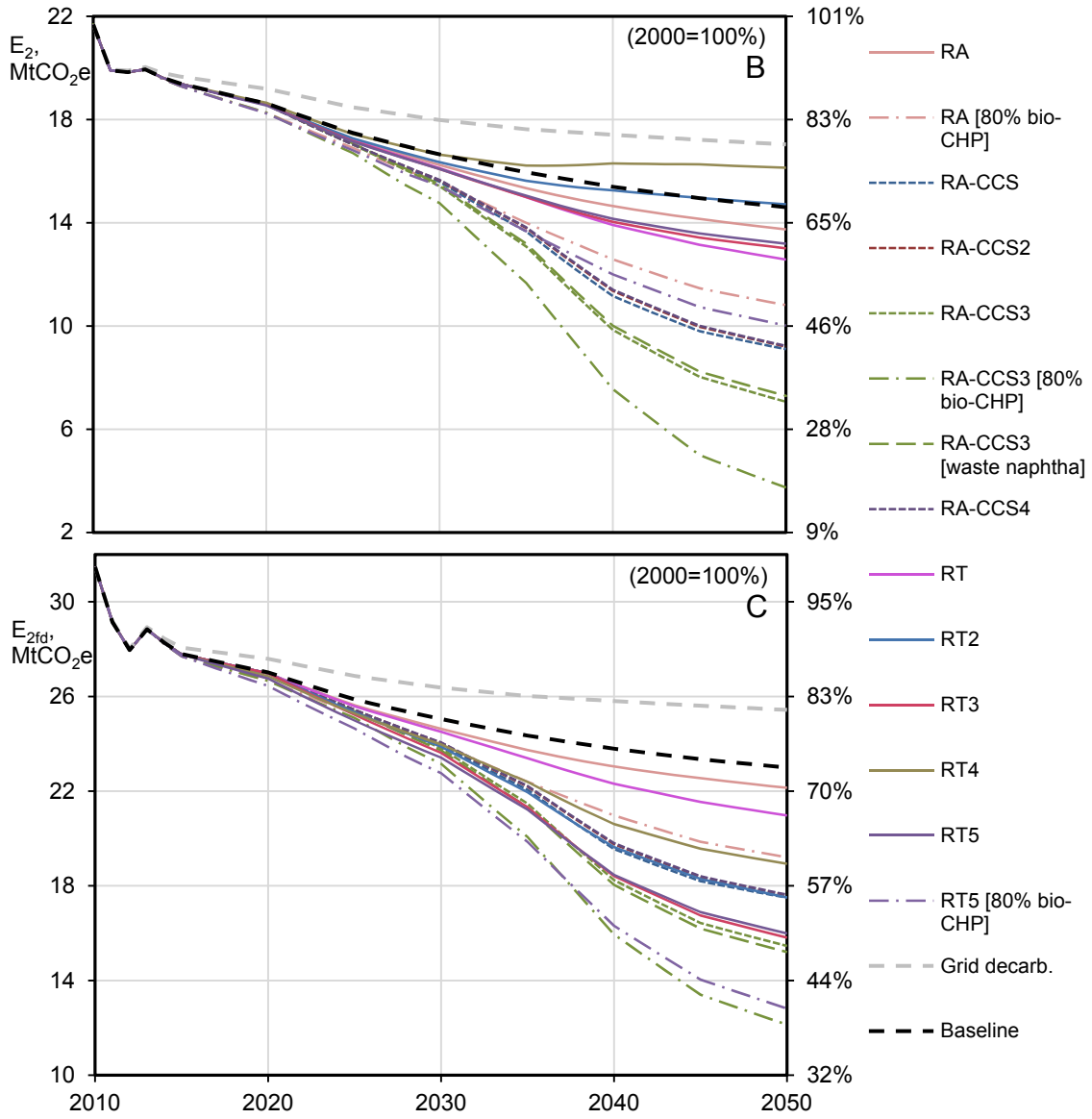

Figure 6-9: GhG emission pathways of technology roadmaps for the UK chemicals sector (credit basis)

Figure 6-8 shows sector GhG emission pathways of the assessed roadmaps and the projected baseline. Graph A includes direct emissions (scope 1) and graph B includes direct and indirect emissions (scope 1-2/3). Graph C includes emission from the combustion of lower olefins on top of Graph B emissions. As emissions in graph C partly derive from feedstock, their measure is denoted by fd. Additional autogeneration plant for alternative lower olefin production routes, as modelled by Ren (2009), are excluded to avoid conflict with existing generation plant and provide a simpler basis for comparison. As electricity and heat are exported from the sector it is useful to analyse the associated emissions by what would otherwise be emitted from public distribution systems. In Figure 6-9 indirect emissions are measured on a credit basis.

Unlike the previous roadmap assessments, trajectories of relevant emission targets are not shown. This is because the wide coverage of sector emissions could not be linked with emissions verified under the EUETS. Furthermore, because of data limitations it was not possible to accurately

determine the extent of sector autogeneration and heat trading over the earlier years. Instead these graphs are used as a way of comparing the future potential of the constructed roadmaps and their relationship with the wider UK system. To aid in this comparison the roadmaps are represented at different sector scopes in section A7.3.1 of the Appendix.

An initial observation is that the pathways in Figure 6-8 are more closely packed together than those in Figure 6-9. In graphs B and C of Figure 6-8 heat and electricity is exported from all pathways with emissions factors calculated from their generation. Roadmaps with lower emissions intensity of generation therefore have a lower emission deducted. The baseline only attains a 10% biomass demand for CHP so it benefits by exporting this heat and electricity to other users to whom the higher emissions factor would be attributed. Conversely, the 80% biomass CHP roadmaps show a narrower improvement on their counterparts and all CCS roadmaps, for which emission is captured from auxiliary generation plant producing surplus electricity, appear less attractive. An indication of the relative degree of decarbonisation of the grid and district heat systems may also be deducted. The CCS and high biomass CHP roadmaps all yield higher 2050 emissions in Figure 6-8 than in Figure 6-9 whereas the opposite is true for the other roadmaps and baseline. Thus the extent of external heat and power decarbonisation is somewhere between.

Graphs A and B show that the radical transition roadmaps abate less than the CCS roadmaps and especially so on a credit basis. However in graph C, which includes emission from the combustion of HVCs, RT roadmaps which use biomass as a feedstock significantly improve in their relative performance. In particular, RT3 (lingo FT naphtha) and RT5 (bio-ETE) abate more than the CCS roadmaps in Figure 6-8 and equate to the same abatement as the RA-CCS3 roadmap in Figure 6-9. The use of waste-derived naphtha, which is limited to replacing 20% of naphtha feedstock, shows only a marginal net improvement in graph C.

Certainly it is critical in this sector to specify the treatment and inclusion of generating plant and feedstock related emission. This may be best understood by comparing graph C of Figure 6-8 with graph B of Figure 6-9. As discussed in section 3.2.1.2, the allocation of generation plant to the industrial sector is not consistent in energy statistics. For example, if chemicals MPPs are allocated to the grid then CCS roadmaps, in which these plant's emissions are captured, have less scope in the chemicals sector. The CCS roadmaps with surplus electricity are also more sensitive to the relative decarbonisation of the national grid. For example, a more aggressive grid decarbonisation would diminish the relative improvement of the CCS roadmaps seen between Figure 6-8 and Figure 6-9. It should be noted, therefore, that the projected grid decarbonisation used for the analysis is conservative compared with paths indicated in policy documents (DECC 2014i, HM Government 2011).

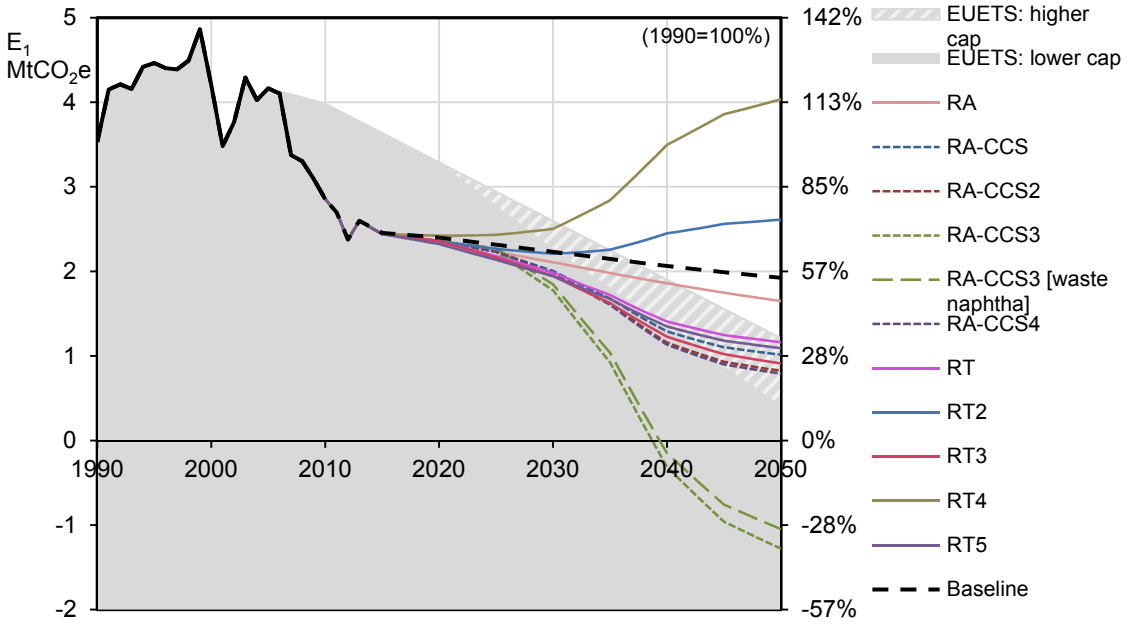

Figure 6-10: GhG emissions pathways of illustrative technology roadmaps for UK petrochemical and petrochemical feedstock production

Figure 6-10 shows the trajectory of the petrochemicals sector against the higher and lower caps of the EUETS. Because the scope of the petrochemicals sector must include feedstock production to enable comparison between lower olefin production routes, the caps shown are proportionally adjusted up from the emissions verified for steam cracking. No constraint specific to this scope of emission exists as the allocation is necessarily site-based. However this comparison provides an indicator of potential for meeting the cap. As observed from Figure 6-8, direct emissions do not account for the whole picture. It can, therefore, be deduced that the EUETS must unfairly incentivise the use of retrofit CCS over bio-based process routes because CCS specifically attends to emissions at the installation.

The UK Carbon Plan emissions trajectory is not shown in Figure 6-10 as its base year was an atypical year for lower olefin production. This exemplifies one of the pitfalls of applying an industry-wide target to specific industrial sectors. The target is thus not a suitable indicator for this assessment.

6.6 Discussion

Lower olefins primarily serve as the building blocks to polymers for the production of plastics, rubbers and fibres. For example, more than half of ethylene is polymerised into polyethylene with most of the remainder forming precursors of other plastics such as Polyvinyl chloride, polystyrene, polyester, and so on (European Commission 2003). A lot of attention in research has been given to the potential for substituting these products with bio-based polymers. In a plenary study by Shen et al. (2009) it was determined that it is technically possible to substitute 90% of the applications for existing petro-based plastics and fibres with bio-based polymer alternatives or counterparts. There are three main approaches to manufacturing bio-based polymers (ibid.):

modify natural polymers, e.g. starch plastics; manufacture biomass derived monomers by fermentation or conventional methods and polymerise; or, directly synthesise from micro-organisms or via genetically modified crops. In this chapter focus was given to the second approach so as to explore improvements or alternative routes to the production of those products for which it was possible to model a baseline. This approach produces chemically identical or similar counterpart products and therefore entails the greatest technical substitution potential. The first approach is forecast to continue to expand in the short-medium term (European Bioplastics 2013) but its scope in plastics applications is more limited. The third approach remains at laboratory scale and its potential is not possible to assess at this stage.

The UK produces some 2.5Mt of primary plastics, or resins, per year and nearly 5Mt of converted plastics, such as packaging, downstream (BPF 2012). As a result the UK is an importer of primary plastics and consumption is in the region of 5Mt. Domestic production of bio-based plastics is presently very low with no large-scale production facilities, although converters are willing to expand their use of bio-based plastics and already import them (Barker and Safford 2009). A feasibility study commissioned by the National Non-Food Crops Centre (NNFCC) suggests that a wheat-based 200kt/yr polylactic acid plant could be commercially viable and encourage the development of a UK-based market. The UK also produces the feedstock for ETE or bio-based polypropylene through its growing bioethanol sector and is well placed to produce wheat starch for starch plastics (HGCA 2009). The market for bio-based polymers today is dominated by these two variants (European Bioplastics 2013).

As the industry is presently in its infancy it cannot be expected to require any significant proportion of crop land-use in the short-medium term. Nonetheless, measures for increasing wheat supply in this time could include the utilisation of set-aside land and yield an additional 2.1Mt/yr (Barker and Safford 2009). In the long-term a further 0.5Mt/yr could be made available from the conversion of temporary grassland and another 2Mt/yr from higher intensity crop rotation (ibid.). However, any strategy to increase feedstock availability should account for the potential environmental impacts of more intensive farming practices.

The UK appears to have the technical and feedstock capabilities, as well as the downstream industrial demand, to develop a bio-based polymers manufacturing industry. As global production capacity for bio-based polymers is expected to grow substantially from 800kt in 2012 and to over 5Mt in 2017 (European Bioplastics 2013), the correct support and incentives should be made available to ensure the UK does not fall behind. This would entail significant public investment to push forward technological development (LCICG 2012).

The prospect of applying CCS is reasonable compared with the sectors of iron and steel, and cement. All steam crackers and ammonia plant are situated within CCS cluster regions (see Figure 5-7, section 5.5). The cost of capture from ammonia is also very low because of the purity

of its process CO_2 emission. Retrofitting post-combustion capture at steam cracker furnaces has been estimated to cost in the range of 28-52£/tCO_2 (Johansson et al. 2012). This range covers the options identified in the study with the lower limit being comparable to oxyfuel capture technology and attained through the utilisation of process waste heat. Unlike oxyfuel capture, however, post-combustion would not require major process modification.

6.7 Summary and conclusions

A bottom-up energy and material database was exploited to examine present and future resource demands and GhG emissions in the UK chemicals sector. Production from 27 processes was estimated from published capacity and feedstock data. Heat and power generation in the sector was modelled alongside petrochemical feedstock production to construct a baseline suitable for key technological replacement opportunities. Key abatement opportunities to 2050 centred on the production of lower olefins and, to a lesser extent, ammonia. All options were modelled with the baseline into a bottom-up technology roadmap projection model. Illustrative roadmaps were designed to map routes to various levels of emissions abatement by 2050.

Improvement to existing processes could yield reductions in energy demand and GhG emissions around a third and a quarter respectively. Beyond this, it was found from a number of technology roadmaps that retrofitting CCS to existing steam cracking, steam reforming, and CHP capacity, or transitioning to bio-based production methods could yield significant emissions reduction within the sector. Regarding the last of these, additional emissions reduction can be attributed to the fixation of carbon in the growth of biomass feedstock. However, these reductions would not be attributed to the sector under the EUETS because they do not reduce emission at the industrial installation. This unfairly incentivises deployment of CCS over alternating bio-processing routes. Regardless, the Government needs to support growth in bio-processing and bio-based polymers to secure a future share of this quickly growing market.

The roadmaps also uncovered key interactions between the sector and the decarbonisation of imported electricity and heat. The treatment and scope of sector generation evidently has a significant influence on the relative performance of technology roadmaps. Further assessment could include a range of decarbonisation scenarios for external and internal generation activities.

Technological data collected for the projection model was sourced exclusively from techno-economic studies (Johansson et al. 2012, Ren 2009) and could therefore be extended to incorporate the associated economic information from these studies (also collected under the UED project). Though in the case of bio-based process routes, further technical and economic information for processes using UK feedstock should be sought. This should also be used to inform for the appropriate sizing and incorporation of ancillary generating capacity to allow for a more detailed assessment in this area.

The baseline for this sector study is less precise than the baselines for steel and cement due to poor data availability and a greater reliance on national energy statistics. Moreover, UK energy statistics for the chemicals sector is inconsistent in scope and consumption of fuels, such as OPG, between sources. Improving the baseline and roadmap technology projection model would require the data of a detailed survey of all energy and feedstock flows specific to all major sites and processes. The baseline could also be adapted and extended by fully integrating the model with the petroleum refineries sector and its opportunities. These developments are necessary to enable a more holistic account of future technological opportunities and their interactions with the wider industrial system.

7 Discussion

The overarching aim of this thesis was to measure the potential for reducing UK energy demand and GhG emissions by radical process change in energy intensive industrial sectors. This reduction is necessarily a long-term pursuit and coincides with 2050 emission reduction targets. Industry is highly diverse in its manufacturing processes and in the way it uses energy, so analysing potential from technological change requires a bottom-up approach on a sector-by-sector basis. Thermodynamic and techno-economic methods quantify potential for improvement from the bottom-up perspective. This measurement is then brought into the context of UK energy and emissions by the use of national statistics.

A number of objectives were outlined alongside the thesis aim in section 1.7. Having set the top-down context in chapter 3, detailed bottom-up studies were then conducted for the iron and steel sector in chapter 4, the cement sector in chapter 5, and the chemicals sector in chapter 6. Technology roadmap projection models were built to analyse potential in each sector out to 2050. As the largest sector in energy and emissions, iron and steel received the most attention. Because of time constraints economic appraisal could only be given to this sector. Although this limitation has prevented economic aggregation and comparison between sectors, the level of transparency and detail applied for the iron and steel sector provides a blueprint on which to extend the appraisal. Focusing attention to within energy intensive industrial sectors also presented a constraint in determining full potential for change. It was identified that material efficiency options could play a key role in realising the best decarbonisation outcomes. However to incorporate this approach would require assessment of the wider industrial and economic system.

In this chapter, results from the preceding four chapters are discussed and combined. In section 7.1, the results are extended by combining the roadmaps and implanting them into a wider energy intensive industry model. In section 7.2, generalisations are drawn from thesis results. In section 7.3, limitations to the results are highlighted. The chapter is then summarised in section 7.4.

7.1 Combining of results

Figure 7-1 displays GhG emissions pathways of illustrative technology roadmaps for UK energy intensive industry over the period 1990-2050. The graph combines roadmaps constructed in chapters 4-6 with a model for the sectors of pulp and paper, lime, glass, and bricks (see section A8.2.1 of the Appendix). None of these sectors were identified as having viable CCS opportunities and only the paper sector was identified for radical process transition. The aluminium sector is excluded here as the last smelter of significance closed in 2012. Also shown are the trajectories of relevant emission targets and caps. It was estimated that EUETS legislation in 2010 covered 94% of direct GhG emissions from energy intensive industry.

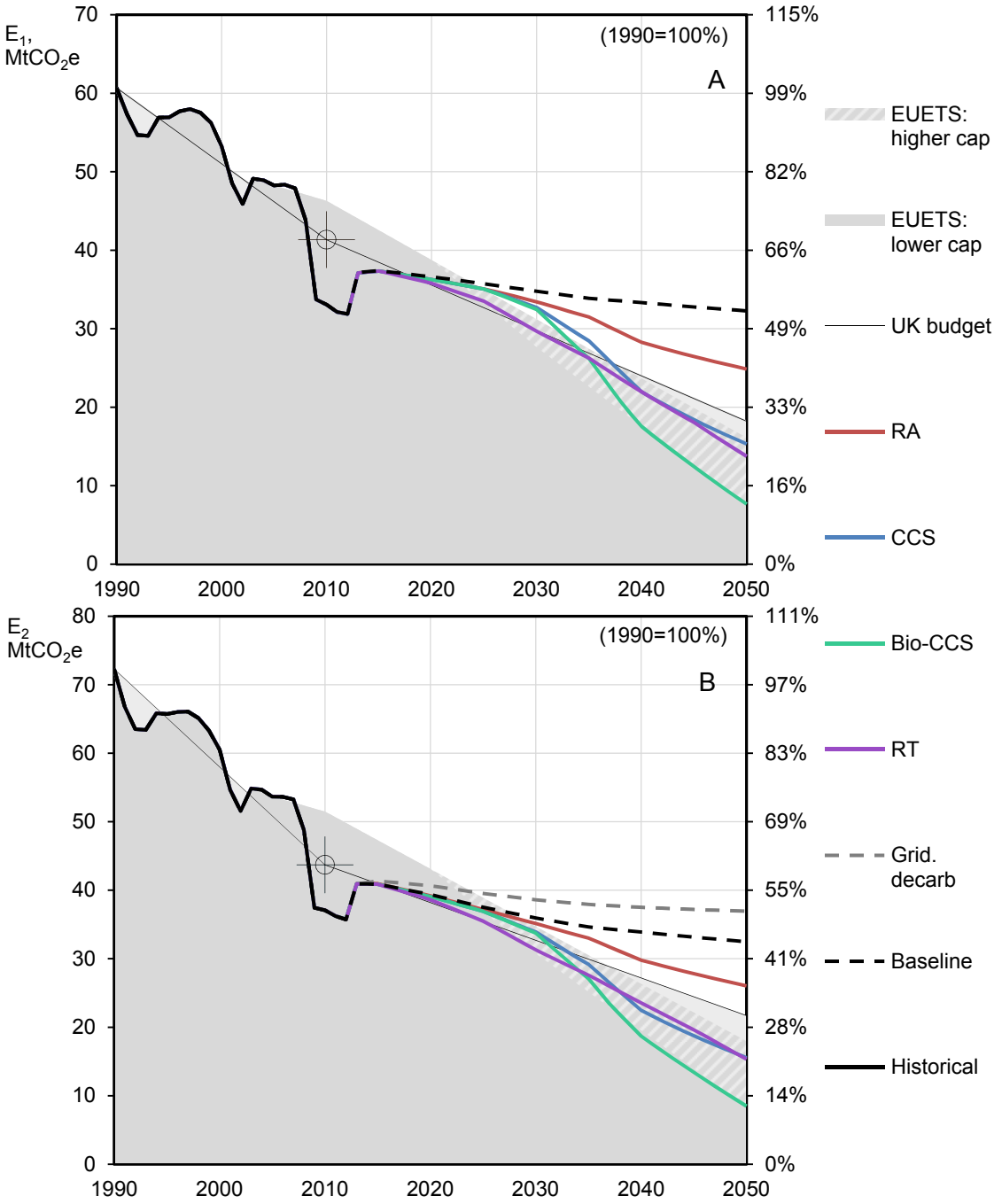

Figure 7-1: GhG emissions pathways of illustrative technology roadmaps for UK energy intensive industry

Roadmap ID	2050 Roadmap description	Fuel demand, PJ (2011-2050)			Energy demand, PJ (2011-2050)			Simple primary energy demand, PJ (2011-2050)			Scope 1 GhG, $MtCO_2e$ (2011-2050)			Scope 1-2/3 GhG, $MtCO_2e$ (2011-2050)			Scope 1 GhG emissions: limit periods, $MtCO_2e$		Scope 1-2/3 GhG emissions: limit periods, $MtCO_2e$	
																	1991-2050	2006-2050	1991-2050	2006-2050
		Absolute	Reduction (%) [2010/1990% in 2050]	Breakthrough reduction {% of total reduction}	Absolute	Reduction (%) [2010/1990% in 2050]	Breakthrough reduction {% of total reduction}	Absolute	Reduction (%) [2010/1990% in 2050]	Breakthrough reduction {% of total reduction}	Absolute	Reduction (%) [2010/1990% in 2050]	Breakthrough reduction {% of total reduction}	Absolute	Reduction (%) [2010/1990% in 2050]	Breakthrough reduction {% of total reduction}	UK budget: 2,190	EUETS high: 1,468 EUETS low: 1,324 (range:1,298-1,351)	UK budget: 2,442	EUETS high: 1,634 EUETS low: 1,473 (range:1,444-1,503)
Baseline	Steel: 67% BAT, 23% BOF scrap, 16% EAF; Cement: 100% BPT, 67% waste fuel of 25% biomass kiln, 35% clinker sub.; Chemicals: 100% BPT steam crackers and steam reformers; Paper: 15% SEC redtn, 40% biomass + 10% waste CHP; Lime: 15% SEC redtn, 33% biomass + 17% waste kiln; Glass: 15% SEC redtn, 33% biogas furnace; Bricks: 15% SEC redtn, 10% biomass + 10% waste kiln.	15,717	-	-	16,723	-	-	18,072	-	-	1,383	-	-	1,446	-	-	2,393	1,590	2,592	1,677
RA	Steel: 67% BAT, 23% BOF scrap, 30% EAF, 28% TGR-BF, 28% HIsarna; Cement: 100% BAT, 80% waste fuel of 50% biomass, 40% clinker sub.; Chemicals: 100% BAT SC + SMR; Paper: as baseline; Lime: as baseline; Glass: as baseline; Bricks: as baseline.	14,791	926 (6%) [21/53%]	-	15,859	865 (5%) [20/53%]	-	17,293	779 (4%) [19/54%]	-	1,280	103 (7%) [25/59%]	-	1,365	81 (6%) [30/64%]	-	2,291	1,487	2,512	1,596
RA-CCS	As RA except- Steel: 28% TGR-BF w/ CCS, 28% HIsarna w/ CCS; Cement: 50% retrofit MEA post-combustion CCS w/ aux. CHP; Chemicals: 100% SC retrofit MEA post-combustion w/ aux. NGCC CHP + SMR process gas capture	15,301	416 (3%) [9/46%]	-510 {-123%}	16,215	508 (3%) [12/48%]	-357 {-70%}	17,491	581 (3%) [14/51%]	-197 {-34%}	1,160	223 (16%) [54/75%]	120 {54%}	1,224	222 (15%) [58/78%]	141 {64%}	2,171	1,367	2,370	1,454
RA-CCS [bio]	As RA-CCS except - Steel: 28% HIsarna w/ CCS and 100% charcoal; Cement: 50% MEA post-combustion CCS w/ 100% biomass aux. CHP; Chemicals: 100% SC retrofit MEA post-combustion w/ aux. biomass boiler/back-pressure-turbine	15,167	550 (4%) [12/48%]	-376 {-68%}	16,232	491 (3%) [11/47%]	-374 {-76%}	17,680	392 (2%) [11/49%]	-386 {-99%}	1,072	311 (22%) [77/87%]	208 {67%}	1,145	301 (21%) [77/88%]	220 {73%}	2,083	1,279	2,291	1,376
RT	As RA except - Steel: 33% EAF, 47% MIDREX, 20% ULCOWIN; Cement: 33% Aether, 10% Celitement, 10% geopolymer, 10% MgO; Chemicals: 67% OCM; Paper: 67% dry-sheet forming.	13,201	2,516 (16%) [48/69%]	1,590 {63%}	14,733	1,990 (12%) [34/61%]	1,125 {57%}	16,806	1,266 (7%) [17/53%]	487 {38%}	1,117	266 (19%) [58/77%]	163 {61%}	1,203	243 (17%) [59/79%]	162 {67%}	2,128	1,324	2,350	1,434

Table 7-1: Cumulative energy and emissions summary of illustrative technology roadmaps for UK energy intensive

The RA roadmap represents a reasonable course of action without breakthrough changes, i.e. radical process change or CCS. The RA-CCS roadmap is based on the RA roadmap but with CCS becoming available. The RA-CCS [bio] roadmap is based on the RA-CCS roadmap but incorporates more biomass and sequesters emissions from its combustion. The RT roadmap represents a radical transition from existing processes. Comparing the breakthrough roadmaps (RA-CCS, RA-CCS [bio], and RT) with RA provides a measure of change specific to the breakthrough measures and technologies (akin to perspective B in section 4.5.5.1). Table 7-1 summarises the roadmaps and their cumulative energy demand and emissions. Split energy demand and GhG emissions by sector are shown for each breakthrough roadmap in Figure 7-2.

Though the CCS roadmaps lead to an energy demand reduction in 2050 compared with the 2010 baseline, they come at significant additional energy demand relative to RA. Deploying CCS technology could have a counteractive effect on fuel demand reduction worth more than half the reduction from the baseline brought by RA, or diminish fuel savings to 45% of what would otherwise be the case. This energy penalty reduces in wider energy terms as the capture system modelled at steam crackers incorporates a CHP plant with surplus electricity generation. The higher primary energy demand associated with combining biomass and CCS results from a marginally lower efficiency associated with the charcoal-based HIsarna and with the biomass boiler and backpressure turbine system applied in the steam cracker capture system. Radical process transition accrues fuel savings worth nearly two thirds (63%) of total fuel savings from its roadmap. In contrast with CCS, the energy *saving* from RT reduces in wider energy terms. This is the result of significant increases in grid electricity purchases to meet demand from electric arc furnaces and electrolysis plant in the iron and steel sector. Such is the sector's electrification in the latter years, primary energy demand from RT in 2050 is comparable to that of RA, though substantially higher energy savings are accumulated over the period to 2050. Nearly 40% of RT roadmap savings are attributable to the technologies of radical process transition.

Scope 1-2/3 GhG emissions reduction in 2050 compared with 1990 levels is 78% with RA-CCS, 88% with RA-CCS [bio], and 79% with RT. Thus all breakthrough roadmaps deliver on the 70% target indicated for industry in the UK Carbon Plan. Though RT and RA-CCS decarbonise by a similar amount in 2050, RT achieves a greater cumulative emissions reduction over the period. This is the effect of deeper reductions from RT over the short-medium term achieved primarily by a quicker move away from blast furnace iron as a proportion of steel production. The difference is also evident between RT and RA; scope 1-2/3 GhG emissions reduction in 2050 from 2010 doubles from RA to RT (30% to 59%) whereas cumulative emissions reduction triples. Of the emissions abated in the breakthrough roadmaps, around two thirds (64-73%) are attributable to the breakthrough technologies themselves.

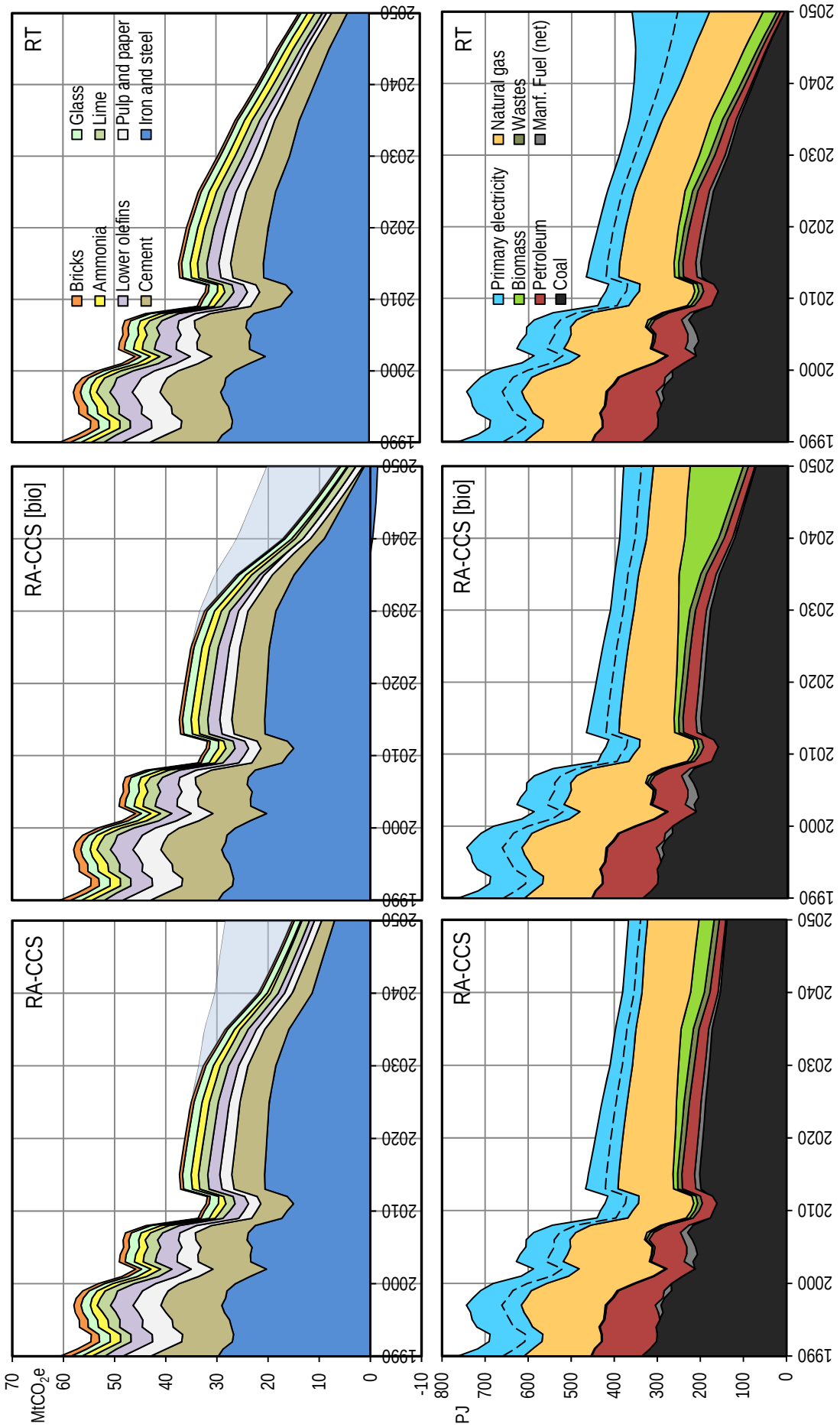

Figure 7-2: Split energy profiles and subsector scope 1 GhG emissions of illustrative technology roadmaps for UK energy intensive industry

At the right hand side of Table 7-1 is listed emissions over periods relevant to the UK budget and the EUETS caps. Of the breakthrough roadmaps only RA-CCS does not comply with the lower EUETS cap range or the UK budget for scope 1 emissions. All breakthrough roadmaps comply if indirect emissions are included. This difference is due to a relatively large decarbonisation from the power sector.

7.2 Generalisation of results

Analysis of energy and GhG emissions in the industrial sector is broadly defined as either bottom-up or top-down. In such a diverse sector the former is a prerequisite for assessing technological change. For some homogenous energy intensive sectors, data at the process level is obtainable and was utilised for the creation bottom-up models of baseline process resource flows. The baselines were placed into the context of top-down energy and emissions statistics. This context was established in chapter 3 by the design of a number of top-down scopes for incorporating bottom-up study and the subsequent creation a top-down/bottom-up framework. Both perspectives were also applied to an examination of energy demand and emissions trends which gave broad insights into the main factors of past changes. The bottom-up baselines account for about a half of direct industrial GhG emissions and about a third of total GhG emissions. Output from energy intensive industry was significantly affected by the recent economic recession and energy price hike, but capacity reduction was less pronounced. This was particularly the case for the iron and steel sector which dominates baseline energy and emissions, and maintains the high demand for coal.

Detailed bottom-up sector studies provide great insight into the characteristics of industrial systems pertinent to energy demand and GhG emissions reduction. These studies were undertaken for the UK industrial sectors of iron and steel (chapter 4), cement (chapter 5), and chemicals with specific focus given to lower olefin and ammonia production (chapter 6). Of central importance are the process plant for major chemical transformations of material feedstock, i.e. the blast furnace, the rotary kiln, the steam cracker, and the steam reformer. Each plant forms part of a wider process system which broadly accounts for the energy and emissions in its sector. The exception here is the chemicals sector, which is heterogeneous in structure and therefore encompasses a wide collection of other distinct process systems[35]. The most complex homogenous process system is that of steelmaking, which is based on an integrated web of material and energy flows. The integrated steelworks site is inflexible and has lower improvement potential than the sum of its constituent steelmaking processes. This is due to the necessary combustion of carbon rich by-products. The production of by-product fuels and process related emissions is why none

[35] These were not modelled in detail due to data unavailability and include, *inter alia*, the Solvay process, the chloride process, and the mercury cell process.

of the analysed sectors can achieve deep emission reductions without replacing existing primary material production methods or applying CCUS technologies.

Another characteristic of the bottom-up modelled systems is the interactive nature of technical change between system components. Replacement processes at the integrated steelworks have a contagion effect on the inputs and outputs of all other components of the manufacturing site, and so need to be modelled by their effect at site level. The cement sector was also modelled with technologies affecting numerous levels of production from clinker to the final cement product. The steam cracker system had to be extended upstream to the petrochemical feedstock production process as replacement process routes substitute both steps.

Interactions manifest themselves as synergies or conflicts to the isolated effect of applying a technology or measure. An example of conflict is the reducing substitution effect of BOF scrap charge with blast furnace improvement or replacement. This is also the case between clinker substitution and kiln efficiency or fuel switching. An example of synergy is the deployment of electric arc furnaces with grid decarbonisation. A novel 'multi-perspective decomposition' assessment of technology roadmaps in the iron and steel sector illustrated interactions between process replacement and crosscutting measures including intermediary product substitution, baseline process efficiency, and grid electricity decarbonisation and efficiency.

The interactions between process system components are also reflected in the dynamics of abatement and production economics, which are themselves the function of resource and carbon prices. In chapter 4 a flexible techno-economic roadmap projection model was built with a detailed representation of cost factors. Present static and future dynamic cost regimes illustrated the opposing effects of an improving baseline and increasing fuel price in the iron and steel sector. Comparison between numerous technology options of different capital and operating costs signalled the dominating influence of resource costs. Emissions are linked to resource use and stepped model runs showed a high sensitivity between carbon price and relative technology or roadmap economics. Most roadmaps are economically favourable to the projected baseline at or above a carbon price that reaches £50/tCO_2 in 2050. The side effect is a production cost increase in absolute terms, i.e. of the alternatives and the baseline together. Only in extreme cases involving a £200/tCO_2 price and a biomass-CCS carbon sink can an absolute production cost increase be avoided and only then at the end of the period to 2050. This is indicative of the requirement for technology push policy measures to accompany existing market pull instruments.

Radical process change is vital for minimising the long-term risks to UK energy intensive industry of not contributing its share of UK and EU emissions reduction targets. This is reflected in the CCS and radical transition roadmap emission pathways from the combined assessment in the previous section and, more specifically, from the steel and cement sector studies. Embraced by sector representatives is the prospect of CCS as a panacea for meeting 2050 emissions targets

incompatible with maintaining production from existing capital assets. Because further improvements to existing processes are limited, keeping these process systems in place will require deeper emissions cuts from 2030 to keep down cumulative emissions over the full period. The availability and economics of CO_2 transport and storage facilities in the UK is uncertain and not least because of the inaccessible location of significant steel and cement production capacity. Radical process change in the iron and steel sector could entail significant DRI and electrolysis technology deployment. Risk may otherwise be alleviated by combining an advanced shift to secondary production from scrap with strategic support for CCU applications and sustainable charcoal resourcing. The cement sector could benefit from maximising fuel switching and clinker substitution from SCMs over the period to 2030 whilst supporting or removing barriers to the development and standardisation of alternative cements. The petrochemicals sector could benefit from support for bio-processing and biomass supply chain development along with incentives for the sector to avoid emissions through the use of biomass feedstock.

7.3 Limitations of results

The results of this thesis apply to the potential for radical process change and other measures within energy intensive industry and so did not account for wider material efficiency opportunities. Energy intensive industry manufactures materials for other parts of industry and construction whereas material efficiency focuses on end-user service and decisions taken downstream of the sectors analysed. Demand for the products of energy intensive industry may be reduced through material efficiency measures including: design for recycling, remanufacture, and reuse; dematerialisation and lightweighting; product longevity; and material substitution. From analysing the potential of these measures to restructure and reduce output from energy intensive industry, a whole range of new roadmaps could be designed within the projection models to account for material efficiency. However, to measure impact on the wider industrial system, an account of other phases along the product lifecycle would need to be considered. Utilising lifecycle analysis (LCA) databases such as the ICE (Hammond and Jones 2011) would bring further insight. Alternatively, the level 2 process analysis conducted in chapter 4 offers a blueprint to producing further such cradle-to-gate assessments that integrate with the projection models.

The industrial sector is global so focusing on UK production does not account for total energy demand and emissions attributable to the UK. Deindustrialisation in the UK has contributed significantly to domestic energy demand and emissions reduction while GDP per capita and demand for material goods has increased. At present the UK is a net importer of steel, plastic, and aluminium (BPF 2012, British Geological Survey 2013, World Steel Association 2013). Thus energy intensive industry, like the UK economy (Barrett et al. 2011), has a higher impact on global emissions when measured on a consumption basis. Only accounting for production emissions may give a false impression of progress and especially so if policies result in carbon

leakage. The assessment undertaken in this thesis framed progress within the context of existing targets for emissions reduction, all of which are production-based. A wider assessment would take account of physical trade flows and industrial technologies operating outside of the UK. The projection models may be converted to measuring consumption-based energy and emissions by changing sector output levels to input levels and designating a proportion of input to that which is imported. Of the imported fraction, energy and emissions intensity conversion factors could be applied based on the relative weighted performance of the exporting countries.

The technology roadmap projection assessments are not forecasts; they are not an attempt to predict the most likely outcome for industry over the period to 2050. Rather, they are scenarios on which to base reasonable comparison between the different roadmaps. The technology roadmaps were designed to be consistent between sectors to build up a picture for energy intensive industry. While they are not forecasts the projections were, however, designed to reflect plausible outcomes. To this end, data on historical production, macroeconomic forecasts, and emissions trading allocation was used to inform for the estimation of future production. Baseline projections were determined by combining this with policy targets on grid decarbonisation and informed estimates of improvement rate towards BAT. Different scenarios of production or of resource economics, e.g. fuel prices, were not explored because the objective was to compare by technology roadmap. Nevertheless, the projection models were developed to enable these scenarios to be investigated. Key variables were also brought into control for updating and refining the existing roadmaps with new information. This could be done by building an 'open source' version of the model and inviting stakeholders and experts to construct their own futures.

The analysis does not cover all aspects or areas of energy intensive industry. The adopted scope for energy intensive industry excluded the petroleum refineries sector. Some assessments of industry exclude this sector, e.g. DECC (2010), while others include it, e.g. Hodges and Hawkes (2010). The main reason for exclusion was the unavailability of detailed data. The UK Petroleum Industry Association releases aggregate data via the DUKES and the GHGI but does not directly provide information at the plant or process level. Moreover, as with the chemicals sector, there exist significant discrepancies in the use of certain fuels between the DUKES and EA datasets. Unavailability of data for the chemicals sector also necessitated the estimation of process outputs and use of European-level efficiency data in chapter 6. Ideally the chemicals and refineries sectors would be combined to properly account for the integrated systems they share and provide a more holistic analysis of the supply chain. In principle, a complete inventory of existing industrial processes, equipment technologies, boilers and generating plant accompanied by detailed allocation of resource flows within the industrial system and its sites would allow for a comprehensive bottom-up coverage of industry. However no such inventory exists nor could one exist without a government backed programme of surveys across industry accompanied by a large provision of privately held data.

8 Conclusions

In this chapter, key conclusions from the thesis are brought together and underlined. In section 8.1, top-level conclusions are provided which sum up the key messages of the thesis. In section 8.2, specific conclusions are summarised and linked to each of the stated objectives from chapter 1. Section 8.3 sets out the thesis' specific contributions to knowledge. In section 8.3, recommendations for further work are suggested. Section 8.4 is the closing statement of the thesis.

8.1 Top-level conclusions

This thesis attempted to answer the question 'what is the long-term potential for energy demand and GhG emissions reduction in UK energy intensive industry from radical change?' This led to a multidisciplinary approach and the utilisation of a 'toolbox' of analysis techniques drawing from thermodynamics, engineering, and economics. Data collected under UKERC's UED project was utilised and built upon in the creation of detailed bottom-up studies of priority sectors of UK industry. Underpinning this was the creation of the UK's first bottom-up technology roadmap projection model for industry. Furthermore, the model is transparent, reproducible, and flexible enough to experiment with key variables and extend the assessment across a range of potential scenarios.

Bottom-up roadmaps are essential to the examination of technological futures in the industrial sector. The industrial sector is considerably diverse and made up of a wide range of independent and interdependent processes and technologies each with their own economics, resource requirements and emissions characteristics. Top-down models do not typically differentiate between technologies, and in those that do it is not possible to measure technological or sectoral improvements accurately. This is because of the absence of a bottom-up system structured at the level of processes. Only with a bottom-up structure can important nuances of energy and emissions pathways, such as progress bottlenecks or replacement and crosscutting technology conflicts, be known. Real techno-economic dynamics may then be understood so as to properly inform present and future economic decision-making.

This thesis has shown that technologically focused industrial policy can be deduced from bottom-up roadmap assessments. Only through detailed bottom-up measurement of cumulative emissions over the course to 2050 can valid comparisons be made between different technology roadmaps by their contribution to meeting the UK's carbon budgets and long-term trajectories of the EUETS cap. The effects of emissions trading on production cost can be quantified, which could inform for investment in public RD&D schemes to accelerate decarbonisation while mitigating the risk of the carbon trading price to competitiveness.

Radical process change is key to UK energy intensive industry realising its long-term potential in energy demand and GhG emissions reduction. This strategy was demonstrated to achieve an 80% reduction in emissions by 2050. Reasonable action accompanied by widespread CCS deployment could achieve similar results but is dependent on timely access to economical CO_2 transport and storage infrastructure. Industry may well rely on a combination of CCUS and process transition but the risk to sufficient cumulative emissions reduction will undoubtedly be increased if process transition is impeded. Nonetheless, the assessment undertaken in this thesis is illustrative and focussed on comparing technological pathways. The model should be further utilised by the development of a broad range of scenarios and adjustment of key variables.

Significant future change in UK energy intensive industry can derive from other parts of the wider industrial system, and bottom-up modelling may assess this. Material efficiency approaches could reduce demand for the products of energy intensive industry. The thesis scope did not allow for the quantification of energy and emissions reduction from a material efficiency approach. However, the bottom-up roadmap projection model clearly demonstrates the capacity to accommodate this strategy. Firstly, because it is possible to quantify on a consumption basis with little modification to the model. And secondly, because the model is built on comprehensive energy and material flow tables enabling for an incorporation of cradle-to-gate considerations, e.g. through level 2 process analyses.

8.2 Meeting thesis objectives

Conclusions are associated here with the objectives laid out in section 1.7.

1. **Provide a brief policy overview relating to energy demand and emissions reduction in energy intensive UK industry and define radical change (chapter 1).**

   The policy landscape as it applies to UK energy intensive industry is at present dominated by the EUETS and the CCL (with CCAs), and is therefore predominantly market-based. This alone is insufficient with respect to technology development and could lead to suboptimal outcomes for emissions reduction and the UK economy. However, a project has been initiated by BIS and DECC with high stakeholder engagement to model technology roadmaps at the subsector level. This instigates the challenging process of designing and establishing an effective role for 'technology push' measures as part of a more balanced programme of policies for achieving deep sector emissions reduction in the future. However, the project is in its early stages and the history of energy efficiency policy in the UK, which is rich in lessons for effective policy development in this area, should be heeded.

   Innovation theory has useful concepts for characterising technological change in industry. Radical process change in energy intensive industry is defined in the present work as 'a

substitution of the incumbent process with another process route to the same product or with the process of a different product fulfilling the same service'. The degree of technical change may be qualitatively measured as evolutionary, major, or radical, based on a simple set of criteria. Radical process change should also be considered alongside other approaches to achieving deep cuts in sector emissions: carbon sequestration and material efficiency.

2. **Overview relevant thermodynamic and economic analysis methodology (chapter 2).**

Thermodynamic analysis can be used to investigate the transfers and transformations of energy within industrial processes and quantify energy loss and degradation. Based on the first law of thermodynamics, energy loss in most industrial processes may be quantified from the balance of mass-flow enthalpies and transfers of work and heat through an open system. Based on the second law of thermodynamics, exergy analysis determines the quality of energy wasted and the thermodynamic limit for improvement. The extent and location of energy degradation within an industrial process system may be scrutinised through the simultaneous application of energy and exergy analysis.

Energy analysis methods apply the concept of energy at numerous levels and to real world systems. Energy efficiency in this realm is generically understood as less energy input for a desired output. The output may be measured on a physical or an economic basis. Physical output indicators provide an objective measure of technical performance and a more accurate measure of change over time. Economic indicators are more appropriate for aggregated datasets and can provide indicative insights into industry in general.

Energy analysis may be classified as either top-down or bottom-up. The former includes the energy analysis techniques of SEA and I-O tables, is based on national or international statistical datasets, and is suited to the use of economic output indicators. The latter generally includes the energy analysis technique of PA, can involve thermodynamic and techno-economic assessment, and requires detailed primary sourced data or data retrieved from companies, industrial statistical bodies, or trade associations.

A techno-economic appraisal must incorporate a discounted cash-flow of all costs and revenues associated with a technology option over its lifetime, and this should be compared with a base case. The base case is also chosen from a number of options and should be determined for projecting an appropriate baseline. MAC curves provide a clear representation of emissions abatement options, their respective abatements, and associated costs, compared with a specified baseline. However, MAC curves are typically presented without data or assumptions and do not capture intertemporal dynamics or path dependencies.

A generic bottom-up approach aims to understand the dynamics of an industrial sector over time. This entails an investigation of energy and emissions over the past, present and future. More specifically, it may entail the construction of a baseline model and subsequent creation of techno-economic roadmap model.

3. **Conduct a top-down assessment of the UK industrial sector by assessing the energy supply structure and historic trends, and illustrate a link between energy statistics and bottom-up data (chapter 3).**

   UK energy and emissions statistics were critiqued and the DUKES dataset was selected for top-down comparison with bottom-up analyses. The DUKES gives a clear account of energy transformation system structure and, unlike the EA dataset, includes data on electricity production and demand. However, the DUKES dataset is generally less disaggregated and has a weaker connection with combustion emissions detailed in the UK GHGI. A simple bridge was constructed between the two datasets to illustrate the differences but a full reconciliation is not possible without knowledge of the data as received by DECC and Ricardo-AEA from data providers.

   The industrial sector may be represented in a number of ways depending on the degree to which industrial autogeneration, heat generation, and the fuel manufacturing industries are included. Including these activities aligns more closely with installation-based data and is more appropriate for linking with bottom-up studies for the reason that integrated industrial sites and process chains would otherwise cross the sector system boundary. Transformation activities may be ascribed to final energy demand flows with primary energy factors. These were calculated using the method of a past analysis of the UK energy system and showed that industry accounted for over a fifth of total primary energy demand in 2010.

   Energy intensive industry was bottom-up modelled and depicted in the context of UK energy statistics to illustrate a top-down/bottom-up link. The identified homogenous sectors which constitute energy intensive industry accounted for about a third of total (scope 1-2/3) industrial GhG emissions in 2010. Their combined GhG emissions have halved since 1990 as have total industrial emissions. Iron and steel has consistently accounted for just below half of GhG emissions from the energy intensive sectors over the period and has maintained the high proportion of coal in the overall energy split.

4. **Produce detailed bottom-up sector studies of the most energy intensive parts of industry, apply thermodynamic and techno-economic analysis, and construct 2050 technology roadmaps (chapters 4-6).**

In chapter 4 a detailed bottom-up thermodynamic and techno-economic study of the UK iron and steel sector was conducted. Sector energy and emissions have reduced significantly since 1990 with a dominant output effect overcoming a counteractive structural effect and a slow-down in intensity reduction since the 1970s and 1980s. The blast furnace is the most efficient energy conversion process but also the largest energy user and a priority for targeting energy efficiency improvements. Between the modelled baseline and existing BAT options, the sector has technical improvement potential in simple primary energy and GhG emissions of 18% and 12% respectively. Most of this is attainable through well-established heat recovery measures but would nevertheless be insufficient for meeting national and European emissions targets. Considerable emission reductions are possible through existing and emerging process substitutions and CCUS, and the application of these measures with biomass. The cost of future technology options relative to the baseline varies considerably and is highly dependent on the cost of resources. The EUETS carbon price also has a significant effect on the relative affordability of future replacement technologies, but acts to increase production cost from the technologies and baseline together. Still, some technologies and configurations could deliver cost savings in the absence of a carbon price. The uncertainty and cost of CO_2 transport and storage capacity for CCS options puts at risk any sufficient reduction in cumulative emissions over the period to 2050. This may be offset somewhat by CCU and charcoal use depending on other process developments. Alternatively, radical process transition may deliver significant savings but at potentially higher costs to industry along with a dependence on grid decarbonisation and increases in the global supply of scrap. The techno-economic roadmap projection model developed for this study provides the means to investigate a wider set of scenarios including radical transition adaption cost, CCS transport and storage cost, and material efficiency futures.

In chapter 5 a detailed bottom-up technological study of the UK cement sector was conducted. The extent to which the cement sector has contracted since 1990 and 2005 has significantly diluted regulatory pressure to reduce energy and emissions. Further emission reductions from fuel switching and energy efficiency are limited by the extent of improvements made hitherto and by their inapplicability to process emissions. Clinker substitution is also limited by its influence on the material properties of cement. CCS or radical process transition may achieve significant emissions reduction. However, post-combustion CCS could double energy intensity and is prohibitively expensive for most UK cement plants, which would therefore depend on advances in more efficient capture technology. Nevertheless, cement plants are bound by their proximity to raw materials and most are situated away from areas likely to benefit from CO_2 transport infrastructure. A number of emerging alternative cement technologies exist implying varying degrees of

technical change. With the most radical options greater uncertainty exists not least because of the conservativeness of the construction industry in Europe and the UK. A less radical option, however, could potentially be deployed with less disruption and contribute a reasonable reduction in emissions. The technology roadmap projection model developed for this study provides the means for further scenario investigation including material efficiency futures, and is designed to incorporate economic data.

In chapter 6 a detailed bottom-up technological study of the UK chemicals sector was conducted. Existing process improvement in the sector could potentially reduce process energy demand by a third and GhG emissions by a quarter. Further savings are available from capturing emissions at steam cracking, steam reforming, and CHP plant, or by radical technical transitions in the petrochemicals sector involving a switch to biomass-based feedstock. Bio-based feedstock sequesters carbon from the atmosphere during its growth and this was modelled to cancel the effect of lower olefin combustion, e.g. from plastic waste incineration. Petroleum-based olefin combustion could also be reduced through the production and use of waste-derived naphtha, though this approach is rather more limited. Nonetheless, the scope of installation-based emissions trading does not internalise to industry the additional emissions avoided from biomass processing or waste avoidance as these measures relate to feedstock change. Another pertinent aspect of the sector is its complex relationship with grid and heat network decarbonisation, and this was explored through multiple analysis scopes. A greater difficulty or unwillingness to disclose process-level information in the chemicals sector made it necessary to build the sector baseline on data of relatively poor quality. Further refinement of the baseline would provide for an improved analysis and it is recommended that the baseline is extended to cover the petroleum refineries sector. To this end, data on the balance of process energy, feedstock use and output flows of integrated refinery and petrochemicals sites would be required. Despite poor data availability, however, the technology roadmap projection model constructed could enable further scenario investigation in the chemicals sector, including material efficiency futures, and is designed to incorporate economic data.

5. **Discuss assessment results and study the combined potential of identified technologies to affect energy demand and GhG emissions in the UK industrial sector out to 2050 (chapter 7).**

The bottom-up models of chapters 4-6 were brought together and combined with the industrial sectors of pulp and paper, lime, glass, and bricks in a bottom-up technology roadmap projection model for energy intensive industry. Common roadmap groups of the preceding studies were combined to represent technology pathways at an aggregate level. Radical transition, CCS, and bio-CCS roadmaps achieving 80-90% abatement in 2050

from 1990 emissions levels were established and compared to the baseline. These breakthrough roadmaps were also compared with the counterfactual 'reasonable action' roadmap to establish the contribution from technologies and measures specific to them. Radical process transition and CCS options account for some two thirds of their respective roadmap emissions reduction against the projected baseline. While bio-CCS achieves the highest decarbonisation, both CCS options come with a significant energy demand increase. The radical transition roadmap illustrates a higher cumulative emissions reduction than the CCS roadmap owed mainly to higher short-medium abatement during which CO_2 capture and storage is not available.

Results of the thesis were generalised and discussed. Some differences between top-down and bottom-up analyses and their results in chapter 3 were highlighted. Key insights specific to bottom-up assessments were then elaborated on. Recognition of technical interactions invisible to top-down assessments was shown. Attention was given to the interactive nature of technologies within process systems and their associated conflictive and synergistic relationships. These interactions are reflected in the dynamics of technological change, energy demand reduction, GhG emissions abatement, and abatement cost. Lastly, the identified risk imposed by counting on a single unproven crosscutting technology, i.e. CCS, as opposed to radical change through multiple technologies was discussed.

8.3 Statement of contribution to knowledge

Summarised below are the contributions of the thesis to knowledge.

1. In chapter 1 the concept of radical change in industry is defined and distinguished among other approaches to energy intensive industrial energy demand and GhG emissions reduction.
2. A method for determining suitable limits on cumulative emissions from industrial sectors based on 2050 targets is established in chapter 1.
3. A fundamental distinction between the definitions of bottom-up and top-down systems is offered in chapter 2 and associated analysis approaches are characterised.
4. A critique of, and data bridge for, UK energy statistics datasets in chapter 3 identifies data inadequacies from a bottom-up perspective and data discrepancies at the top-down level.
5. A calculation of primary energy factors in chapter 3 provides the means to accurately convert all final demand sectors in DUKES energy statistics to primary energy demand, and updates on previous research by applying analysis to more energy transformation activity and by introducing the primary energy commodity factor.

6. Top-down scopes and definitions in chapter 3 frame bottom-up modelling in UK industry and bottom-up baselines provide a recent snapshot of energy and GhG emissions from key energy intensive industrial sectors.
7. An interdisciplinary assessment of the UK iron and steel sector in chapter 4 combines thermodynamic, technical, and economic analyses and contributes a range of new and up-to-date quantitative and qualitative outputs. Included is:
    a. A detailed survey of past and present technical status, and subsequent establishment of a technical, energy, material, and emissions baseline.
    b. A decomposition analysis of past intensity, structure, and output effects on energy demand and GhG emissions at multiple levels of the steelmaking process.
    c. An IFIAS process analysis of present and historic PER, NER and GER of sector and process routes, updating and expanding on a 1982 study of the Energy Audit Scheme (Energy Audit Series 1982).
    d. A detailed thermodynamic analysis of process plant and routes updating and expanding on a past UK assessment of specific UK steelworks sites (Michaelis 1998). Energy and exergy Sankey diagrams are produced applying the 'band diagram' format introduced by Szargut et al. (1988).
    e. A BAT and BPT standard is presented and used to analyse technical improvement potential at the process and site level, and compare with theoretical and thermodynamic improvement potential.
    f. A dichotomy of 'present static' and 'future dynamic' regimes of techno-economic assessment is introduced and demonstrated.
    g. A novel 'multi-perspective decomposition' represents future technological change in the sector by attributing energy demand and emissions change in different ways.
    h. A dynamic economic representation of technology roadmaps is provided.
8. A bottom-up assessment in chapter 5 models a technical, energy, material, and emissions baseline for the UK cement sector and determines scope for improvement against policy related emissions limits.
9. A bottom-up assessment in chapter 6 models a technical, energy, material, and emissions baseline for the UK chemicals sector and determines scope for improvement with comparison of multiple emissions scopes and reference to policy related emissions limits in the petrochemicals sector.
10. The complex relationship that can exist between an industrial sector and the wider electricity and heat supply system is demonstrated in chapter 6.
11. A bottom-up techno-economic roadmap projection model for investigating futures in the UK iron and steel sector is built in chapter 4. The model is unprecedented in flexibility and detail, and provides a usable tool for extending the roadmap analysis conducted

therein. The model also demonstrates a transparent analysis approach so that outputs may be reproduced and updated.

12. Bottom-up technology roadmap projection models are built in chapter 5 and chapter 6 for the UK cement and chemicals sectors respectively. The models follow the same format and approach as that in chapter 4.
13. A bottom-up technology roadmap projection model is built in chapter 7 for assessing futures in the UK industrial sectors of pulp and paper, lime, glass, and bricks. The model integrates with the bottom-up models of chapters 4-6 and provides a tool for extending the roadmap analysis of UK energy intensive industry.
14. Sector, site, and technology energy and material flow balances from a previous database project are updated and 130 new site configurations are constructed for technology deployment in the UK iron and steel sector.

8.4 Recommendations for future work

Summarised below are recommendations for future work to build on the contributions of the present work.

1. Use bottom-up roadmap projection modelling with a wider assessment of material efficiency to compare this approach with the approaches of radical process change and carbon sequestration in energy intensive industry.
2. Refine and improve the modelling by updating techno-economic variables and assumptions, and by introducing wider scenarios and sensitivity analyses.
3. Modify the bottom-up roadmap projection models to more accurately measure industrial energy and emissions change on a consumption basis.
4. Extend bottom-up modelling of UK energy intensive industry to incorporate economic appraisal across all of the studied sectors.
5. Build on the IFIAS process analyses of UK iron and steel production to create a database of cradle-to-gate energy demand and emissions from which to compare the effects of downstream approaches such as dematerialisation, material substitution, and so on.
6. Widen the scope of assessment by bottom-up modelling the refineries sector and other chemicals sector processes. The food and drink sector is another possible consideration.
7. Develop a fully integrated bottom-up projection model between all energy intensive sectors with newly sourced data for areas of poor data quality, and the capacity to cost optimise roadmaps across energy intensive industry.
8. Create an open source version of the model to allow for stakeholders, experts and other interested parties to develop their own roadmaps and scenarios.

8.5 Closing statement

To quantify long-term energy demand and GhG emissions reduction from radical change in UK energy intensive industry, this thesis has provided an impartial and transparent assessment of unprecedented detail. A multi-disciplinary approach demonstrated the use of numerous analysis techniques to provide an in-depth account of the most important industrial sectors. Flexible bottom-up technology roadmap projection models were built and provide a platform for further research in this area. These models captured the interactive and complex technological change dynamics that characterise the industrial system. The work has demonstrated the worth of a usable energy database and adds to a growing interest from public and private stakeholders in technology roadmaps for informing decisions to accelerate long-term emissions abatement. Future work should aim to build on the modelling with economic appraisal across all sectors and an incorporation of wider material efficiency approaches.

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Appendix

A1 Projecting cumulative GhG emissions in the UK

Figure A-1 illustrates the maximum cap on GhG emissions entailed by agree Carbon Budgets. This is assumed to be the emissions resulting from a linearly reducing path from 50% in 2025 to 80% in 2050 from 1990 levels. The resulting budget is 27.7GtCO_2e over the years 1991-2050 and 13.9GtCO_2e over the years 2011-2050. Targets contributions to the budget from individual sectors have not been made explicit. However, the Carbon Plan (HM Government 2011) indicates that emissions in 2050 from industry could require a 70% reduction in the industrial sector from 1990 levels* with higher reductions from transport and buildings.

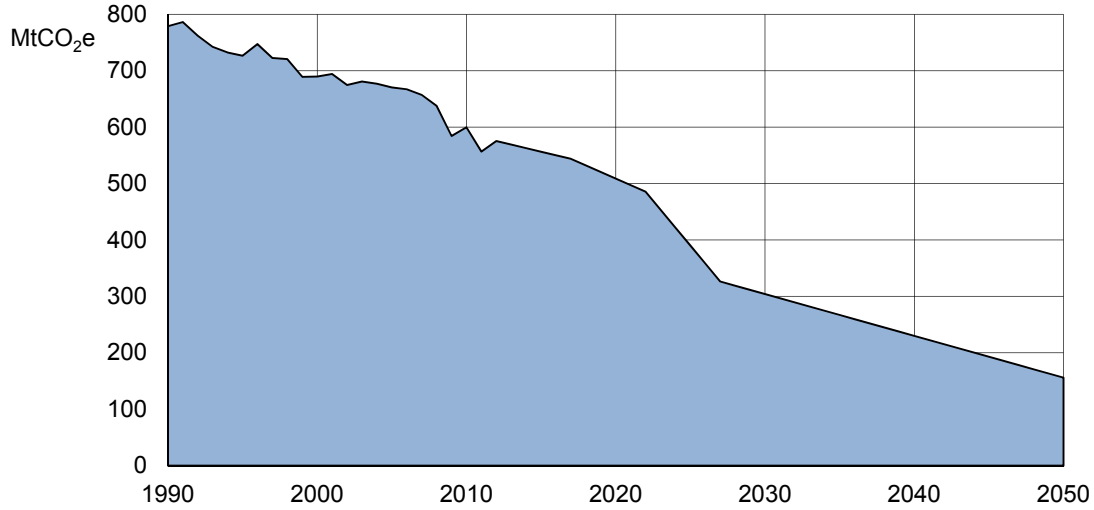

Figure A-1: Maximum UK emissions cap assumed as linear extrapolation from fourth UK carbon budget

Figure A-2 shows how cumulative industrial emissions may be modelled around a 2050 target using linear pathways. Historical emissions are accounted for by the linear path yielding that emission. Projected emissions assume a linear path to the reduction target in 2050. This approach ensures that reduction from industrial subsectors will amount to the required industrial total whilst taking into account the historical contribution specific to each subsector. As the chosen baseline for projections is 2010, historical cumulative emissions include the years of 1991-2010, and projected cumulative emissions include the years of 2011-2050. For industry the resulting budget is 7.7GtCO_2e over the former period and 4GtCO_2e over the latter.

* The source document does not make explicit whether the 70% reduction covers the period 1990-2050 although this is strongly implied by an accompanying statement referring to the target as industry's contribution to the national 80% target. Moreover, were the 70% target a reduction from the 2009 status outlined elsewhere in the document then, based on historical data (ONS 2014e), this would equate to a reduction surpassing 80% from 1990 levels despite deeper reductions planned in buildings and transport.

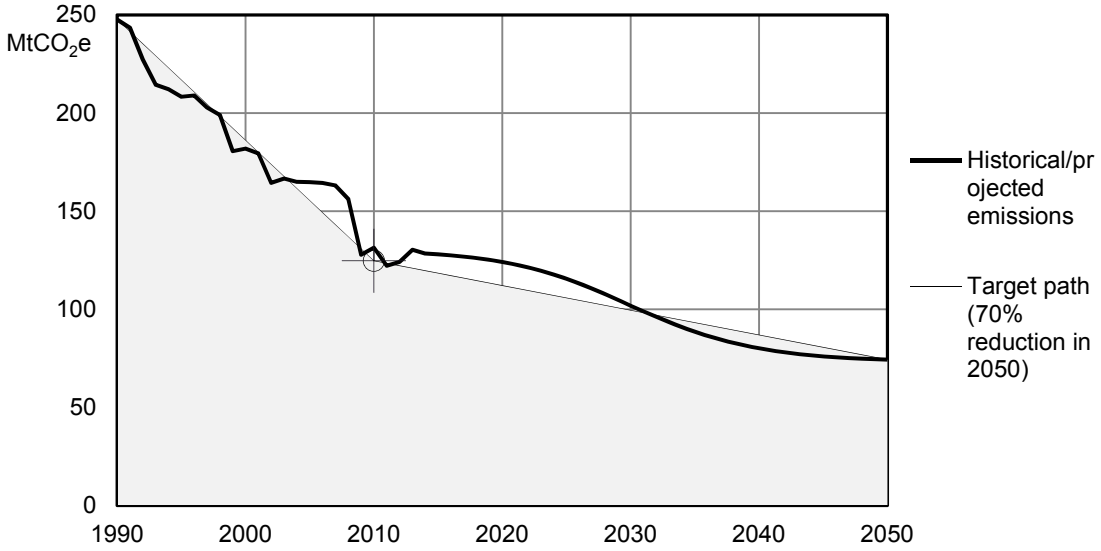

Figure A-2: Illustrative example of the adopted method for translating 2050 emissions targets into cumulative emissions limits for UK industry

The Carbon Plan specifies that the 70% reduction applies to overall emissions which would imply the inclusion of indirect emissions from the purchase of electricity. A proportionally higher level of decarbonisation is envisaged in the electricity supply sector (HM Government 2011) which would entail a slightly less stringent challenge regarding direct emissions from industry. The difference depends on the level of electricity decarbonisation and the proportion of industrial emissions deriving from electricity purchases. On the basis that the target is only indicative, a 70% reduction is also assumed of direct industrial emissions.

A2 Top-down statistics data bridge

PJ		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Energy accounts - Manufacturing		**1740.4**	**1739.3**	**1683.7**	**1580.2**	**1610.3**	**1616.6**	**1596.0**	**1572.8**	**1538.3**	**1488.7**	**1311.0**	**1302.7**	**1279.1**	**1230.8**
Fuels excluded from DUKES	(-)	**219.7**	**225.3**	**221.5**	**211.8**	**226.0**	**229.4**	**228.3**	**225.6**	**221.0**	**190.1**	**170.2**	**173.1**	**166.2**	**169.4**
Petroleum Gas use in separation plants		16.4	14.9	19.9	13.4	21.2	19.9	19.9	16.5	18.0	18.5	18.0	16.2	15.0	12.9
OPG & petroluem coke industrial combustion		83.3	91.7	85.2	82.5	89.8	94.9	90.8	94.5	82.8	67.7	64.8	68.0	66.7	70.0
Waste solvents and waste oils		3.3	3.4	3.2	2.9	3.0	3.3	3.3	4.6	5.4	4.4	3.4	3.9	3.7	3.7
Transport and off-road industrial machines		116.8	115.3	113.3	113.0	112.0	111.3	114.3	110.0	114.8	99.5	84.0	85.0	80.8	82.8
Fuels excluded from Energy Accounts	(+)	**471.5**	**482.2**	**464.0**	**471.1**	**463.2**	**459.0**	**474.4**	**468.9**	**469.2**	**485.9**	**416.5**	**440.4**	**431.4**	**414.3**
Electricity (industry only)		399.5	410.8	400.8	396.6	393.4	401.3	417.7	413.6	406.1	410.9	359.1	376.3	368.5	352.2
Heat (industry only)		45.5	46.0	41.9	55.3	47.2	34.8	34.8	33.9	37.5	42.7	31.9	34.4	32.2	33.3
Renewables & waste		11.8	11.1	10.2	10.5	11.2	11.1	8.4	8.9	11.6	17.3	17.4	18.8	21.2	20.4
Tar and benzole		8.4	8.6	7.6	6.4	6.4	6.2	6.3	6.7	6.6	6.5	5.5	6.1	6.0	5.6
Blast furnace gas loss		6.2	5.7	3.5	2.3	5.0	5.6	7.3	5.7	7.5	8.4	2.6	4.8	3.6	2.9
Fuels for heat and power generation	(-)	**250.3**	**264.4**	**231.1**	**229.7**	**238.4**	**242.7**	**242.9**	**229.2**	**242.7**	**235.5**	**212.5**	**202.0**	**199.1**	**196.4**
Fuels for exported heat (excluding public administration and commercial)		82.7	84.0	77.9	68.8	54.4	62.5	65.6	62.5	68.9	75.7	65.5	69.1	69.1	67.7
Autogenerators (excluding renewables and waste)		167.6	180.4	153.2	160.9	184.0	180.3	177.3	166.7	173.8	159.8	147.0	132.9	130.0	128.7
Sector coverage	(-)	**412.1**	**377.9**	**335.7**	**341.3**	**355.1**	**372.2**	**383.0**	**362.2**	**360.7**	**370.5**	**313.8**	**299.5**	**308.0**	**303.2**
Additional sectors to manufacturing: 08, 36-39, 41-43		-40.0	-48.7	-67.4	-51.6	-45.8	-33.4	-37.2	-33.7	-34.0	-32.9	-25.7	-27.5	-24.1	-15.6
Excluded energy sectors from manufacturing: 19, 24.46, 23.1 (part)		452.1	426.6	403.0	392.9	400.9	405.5	420.2	395.9	394.7	403.3	339.5	327.0	332.0	318.8
Coke ovens (net)		43.3	42.2	31.9	18.6	15.9	17.4	17.8	19.2	23.9	27.0	32.7	23.7	26.4	27.4
Blast furnaces (net)		140.5	130.1	123.7	104.7	125.6	125.3	125.1	134.9	136.7	136.9	100.1	90.8	85.9	93.2
Petroleum refineries		261.1	246.6	242.0	265.1	253.0	254.3	268.6	234.7	224.6	228.9	206.5	208.9	215.7	197.9
Patent fuel (net)		0.4	0.8	1.1	0.7	-0.3	0.1	-0.1	-0.3	0.4	0.7	-2.6	-3.4	-2.3	-3.3
Losses (blast furnace gas and coke oven gas)		6.8	6.9	4.3	3.7	6.7	8.4	8.8	7.4	9.1	9.9	2.9	7.0	6.3	3.6
Statistical error	(+)	**103.1**	**132.5**	**124.5**	**145.1**	**172.6**	**146.6**	**135.4**	**90.9**	**94.8**	**82.9**	**64.5**	**55.7**	**47.3**	**77.4**
OPG & petroleum coke (refineries)		-1.8	-2.8	-4.3	-2.6	-0.5	-25.7	0.1	-39.9	-32.4	-36.4	-42.4	-33.5	-45.8	-31.8
Gas oil difference (industrial combustion)		97.2	111.8	131.1	130.5	147.6	132.3	116.5	112.6	111.6	101.0	85.3	83.2	67.8	81.1
Autogenerators difference (natural gas and coal)		8.2	9.6	6.6	12.7	11.2	8.5	9.9	9.1	9.1	9.4	7.4	6.7	5.7	3.4
Burning oil difference		12.7	19.2	22.1	18.9	18.7	20.9	22.1	22.8	20.9	21.2	21.3	21.7	19.3	19.6
Not elsewhere classified		-13.3	-5.3	-31.1	-14.4	-4.4	10.5	-13.3	-13.7	-14.4	-12.2	-7.1	-22.4	0.3	5.1
Adjusted total		**1432.8**	**1486.6**	**1483.9**	**1413.6**	**1426.6**	**1378.0**	**1351.6**	**1315.6**	**1277.9**	**1261.6**	**1095.5**	**1124.2**	**1084.5**	**1053.6**
DUKES - Industry		**1432.8**	**1486.6**	**1483.9**	**1413.6**	**1426.6**	**1378.0**	**1351.6**	**1315.6**	**1277.9**	**1261.6**	**1095.5**	**1124.2**	**1084.5**	**1053.6**

Table A-1: Illustrative industrial energy statistics data bridge for the UK industrial sector from the ONS Energy Accounts to the Digest of UK Energy Statistics (DECC 2013a, ONS 2014b)

A3 Top-down analysis background analysis

This section contains tables and figures relating to detailed background calculations conducted in chapter 3 for the purpose of determining a link between bottom-up study and top-down statistics.

Table A-2 is a modification of the DUKES 2010 aggregate energy balance to include the full split fuels and additional energy user categories. Various updates to the DUKES dataset were identified in chapter 3 and these are indicated in Table A-3 by the figures in red. Further updates to the industrial sector were reported in the latest edition of the DUKES (DECC 2014b) whereby some final energy demand was reallocated from the industrial sector to the commercial sector. Key figures affected from this are highlighted in blue. These specific changes have not been incorporated into this table nor the analysis of this thesis as they would prevent fair comparison with the latest EA dataset (ONS 2014b), a large part of which is based on the preceding edition of the DUKES (DECC 2013a).

Top-down/bottom-up frameworks are depicted in Table A-4, Table A-5, and Table A-6. The discrepancy in total energy demand of about 1.7PJ between Table A-3 and Table A-4 is the difference in the production and consumption of certain by-products (blast furnace gas and coke oven gas), which were adjusted to be in balance for the analysis.

Figure A-3 shows decompositions of energy data deriving from the EA dataset that supplement Figure 3-8 in section 3.5. The three graphs show fuel, direct energy, and primary energy (primary energy is termed reallocated energy in the EA dataset (ONS 2014a, 2014d)). The definition of industry excludes fuel manufacturing (19), except for coke production which is reallocated to the iron and steel sector. Industrial autogeneration is included whereas energy for transport and industrial off-road mobile machinery is excluded.

DUKES 2013 - Disaggregated 2010 PJ	Coal	Coke	Coke breeze	Coke oven gas	Tar and benzole	Blast furnace gas	Other solid fuels	Primary oils	Ethane	Propane	Butane	Other gases	Naphtha	Aviation spirit	Motor spirit	White Spirit & SBP 4	Aviation turbine fuel	Burning oil	DERV	Gas oil	Fuel oils	Lubri-cants	Bitu-men	Petroleum coke	Misc. products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	MPP electricity	Industry autogen.	Other autogen.	Heat sold	Total
Supply																																
Indigenous production	480.2	0.0	0.0	0.0	0.0	0.0	0.0	2888.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2394.3	216.8	632.7	0.0			0.0	6612.2
Imports	716.8	1.3	2.1	0.0	0.0	0.0	0.3	2517.7	0.0	8.0	9.8	0.0	32.1	1.1	135.2	8.5	339.2	44.8	348.7	32.1	44.1	27.4	16.7	27.0	5.4	2122.2	80.7	0.0	25.7			0.0	6547.0
Exports	-22.5	-13.0	-1.4	0.0	0.0	0.0	-1.1	-1932.3	0.0	-26.1	-10.0	0.0	-65.5	0.0	-406.3	-1.2	-68.8	-8.8	-96.9	-197.6	-212.3	-19.1	-8.5	-24.5	-44.1	-635.0	-7.9	0.0	36.3	-19.2	-33.2	0.0	-3819.0
Marine bunkers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-71.9	-76.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-148.7
Stock change(4)	192.8	-4.3	-2.5	0.0	0.0	0.0	0.4	-1.7	0.0	-2.3	1.5	0.0	-0.1	0.1	13.8	0.0	5.4	-0.2	2.8	4.3	5.0	-0.8	-4.0	1.9	-0.3	55.0	0.0	0.0	0.0			0.0	266.8
Primary supply	**1367.4**	**-16.0**	**-1.8**	0.0	0.0	0.0	**-0.4**	**3471.9**	0.0	**-20.3**	**1.3**	0.0	**-33.5**	**1.2**	**-257.3**	**7.4**	**275.8**	**35.8**	**254.6**	**-233.0**	**-239.9**	**7.5**	**4.2**	**4.3**	**-39.1**	**3936.4**	**289.6**	**632.7**	**62.0**	**-19.2**	**-33.2**	0.0	**9458.2**
Statistical difference(5)	**0.3**	0.0	**0.0**	**-0.2**	0.0	**-0.3**	**-0.2**	**-1.8**	**0.5**	**1.2**	**3.2**	**0.3**	**-0.8**	**0.2**	**0.9**	**0.1**	**-0.5**	**-0.8**	**-0.3**	**-2.5**	**0.2**	**0.1**	**1.4**	**0.4**	**1.0**	**-9.1**	0.0	0.0	**-1.6**			0.0	**-8.3**
Primary demand	**1367.1**	**-16.0**	**-1.8**	**0.2**	0.0	**0.3**	**-0.2**	**3473.7**	**-0.5**	**-21.5**	**-1.9**	**-0.3**	**-32.7**	**1.0**	**-258.2**	**7.3**	**276.3**	**36.6**	**255.0**	**-230.5**	**-240.1**	**7.4**	**2.8**	**3.8**	**-40.1**	**3945.6**	**289.6**	**632.7**	**63.5**	**-19.2**	**-33.2**	0.0	**9466.5**
	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0	0.0
Transfers	0.0	-24.8	24.8	1.0	0.0	0.0	0.0	-111.4	50.9	35.4	16.5	0.0	6.6	0.0	7.8	0.0	-29.9	30.2	-8.2	2.5	-1.0	0.0	0.9	0.0	-0.3	-0.9	0.0	-49.7	49.7			0.0	-0.004
Transformation	**-1295.2**	**42.8**	**-10.5**	**21.0**	**6.1**	**21.5**	**10.4**	**-3362.3**	0.0	**78.9**	**31.5**	**136.2**	**76.3**	0.0	**938.1**	**3.1**	**267.0**	**118.6**	**699.9**	**427.2**	**300.5**	**18.7**	**57.8**	**69.3**	**70.4**	**-1430.3**	**-185.7**	**-583.0**	**1201.6**	**57.4**	**54.2**	**57.0**	**-2101.3**
Electricity generation	-1070.0	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.0	-22.9	0.0	0.0	-6.1	0.0	-1344.9	-184.0	-583.0	1201.6	57.4	54.2	0.0	-1944.7
Major power producers	-1037.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	-17.2	0.0	0.0	-6.1	0.0	-1231.7	-42.4	-583.0	1201.6			0.0	-1718.1
Autogenerators	-32.7	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-5.7	0.0	0.0	0.0	0.0	-113.2	-141.5	0.0	0.0	57.4	54.2	0.0	-226.7
Industry	-32.6	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	0.0	0.0	0.0	0.0	-70.7	-89.8	0.0	0.0	57.4	0.0	0.0	-165.3
Non-industry	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-5.3	0.0	0.0	0.0	0.0	-42.5	-51.7	0.0	0.0	0.0	54.2	0.0	-61.4
Heat generation	-12.1	0.0	0.0	-1.5	0.0	-0.6	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-2.3	0.0	0.0	0.0	0.0	-85.3	-1.7	0.0	0.0			56.966	-47.1
Industry	-9.3	0.0	0.0	-1.5	0.0	-0.6	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-2.3	0.0	0.0	0.0	0.0	-54.8	-1.3	0.0	0.0	0.0	0.0	38.5	-31.9
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-5.3	0.0	0.0	0.0	0.0	0.0	3.1	-2.5
Non-industry	-2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-30.5	-0.4	0.0	0.0	0.0	0.0	18.4	-15.3
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3362.3		79.2	31.5	151.9	76.3		938.1	3.1	267.0	118.6	699.9	430.5	326.0	18.7	57.8	75.3	70.4	0.0	0.0	0.0	0.0			0.0	-17.9
Coke manufacture	-172.7	118.9	1.0	31.8	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-14.9
Iron and steel	-149.5	111.2	0.9	27.7	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.9
Blast furnaces	-29.9	-76.1	-11.5	0.0	0.0	41.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-76.6
Patent fuel manufacture	-10.6	0.0	0.0	0.0	0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-0.2
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
Energy industry use	**0.1**	0.0	0.0	**15.2**	0.0	**13.2**	0.0	0.0	0.0	0.0	0.0	**126.4**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**22.4**	**22.6**	0.0	0.0	**46.1**	0.0	**248.6**	0.0	0.0	**81.2**	0.0	**11.8**	**3.9**	**591.7**
Electricity generation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.0			0.0	58.0
Oil and gas extraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	0.0	0.0	0.0	0.0	0.0	220.0	0.0	0.0	1.3		0.7	0.0	244.5
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.6	0.0	0.0	46.1	0.0	13.8	0.0	0.0	11.8		6.3	3.9	231.0
Coal extraction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	2.2		1.2	0.0	3.9
Coke manufacture	0.0	0.0	0.0	13.9	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2		0.1	0.0	16.9
Iron and steel	0.0	0.0	0.0	14.1	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	17.0
Blast furnaces	0.0	0.0	0.0	1.3	0.0	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	1.1			0.0	15.3
Patent fuel manufacture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Pumped storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5		1.3	0.0	3.8
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0	0.0	4.1		2.2	0.0	18.3
Losses	0.0	0.0	0.0	**2.2**	0.0	**4.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**67.5**	0.0	0.0	**97.3**			0.0	**171.8**
Final consumption	**71.7**	**2.0**	**12.5**	**4.8**	**6.1**	**3.6**	**10.1**	0.0	**50.4**	**92.7**	**46.1**	**9.4**	**50.2**	**1.0**	**687.6**	**10.4**	**513.5**	**185.5**	**946.7**	**176.8**	**36.9**	**26.0**	**61.4**	**27.0**	**30.1**	**2198.3**	**103.9**	0.0	**1136.3**	**38.2**	**9.2**	**53.0**	**6601.6**
Industry	**47.6**	**1.6**	**12.5**	**4.8**	**6.1**	**3.6**	0.0	0.0	0.0	**13.7**	**13.3**	0.0	0.0	0.0	0.0	0.0	0.0	**68.9**	0.0	**86.5**	**24.3**	0.0	0.0	0.0	0.0	**411.9**	**18.8**	0.0	**338.1**	**38.2**	0.0	**34.4**	**1124.2**
Unclassified	0.0	1.4	0.1	0.7	6.1	0.0	0.0	0.0	0.0	13.6	13.3	0.0	0.0	0.0	0.0	0.0	0.0	68.9	0.0	21.0	4.3	0.0	0.0	0.0	0.0	0.1	18.8	0.0	0.0			0.0	148.3
Iron and steel	1.8	0.2	12.4	4.0	0.0	3.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	21.0	0.0	0.0	-0.2	14.0		0.0	57.2
Non-ferrous metals	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	24.2	0.0		0.0	34.3
Mineral products	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	1.6	0.0	0.0	0.0	0.0	55.6	0.0	0.0	26.2	0.0		0.0	123.2
Chemicals	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	5.8	0.0	0.0	0.0	0.0	77.9	0.0	0.0	57.0	9.4		17.4	176.9
Mechanical engineering etc	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.1	0.0	0.0	26.2	1.4		0.0	51.0
Electrical engineering etc	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	24.0	0.0		0.0	35.1
Vehicles	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	31.4	0.0	0.0	19.0	0.0		0.0	55.5
Food, beverages etc	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.8	12.2	0.0	0.0	0.0	0.0	78.6	0.0	0.0	36.9	4.5		0.0	166.3
Textiles, leather etc	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	11.0	0.0		0.0	35.3
Paper, printing etc	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	52.9	0.0	0.0	34.8	4.7		0.1	99.7
Other industries	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.2	0.0	0.0	0.0	0.0	25.0	0.0	0.0	73.1	4.3		16.9	127.2
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	5.8			0.0	14.2
Transport (6)	**0.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.2**	0.0	0.0	0.0	**1.0**	**687.6**	0.0	**513.5**	0.0	**946.7**	**34.7**	**7.6**	0.0	0.0	0.0	0.0	0.0	**51.0**	0.0	**12.8**	0.0	**1.8**	0.0	**2262.5**
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	513.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	514.5
Rail	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8		1.8	0.0	42.8
Road	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	687.6	0.0	0.0	0.0	946.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.0	0.0	0.1		0.0	0.0	1690.6
National navigation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	14.7
Pipelines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Other	**23.6**	**0.3**	0.0	0.0	0.0	0.0	**10.1**	0.0	0.0	**23.2**	**2.2**	0.0	0.0	0.0	0.0	0.0	0.0	**116.6**	0.0	**49.2**	**5.1**	0.0	0.0	0.0	0.0	**1757.4**	**34.1**	0.0	**785.4**	0.0	**7.4**	**18.6**	**2833.1**
Domestic	22.4	0.3	0.0	0.0	0.0	0.0	10.1	0.0	0.0	17.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	116.6	0.0	7.5	0.0	0.0	0.0	0.0	0.0	1402.5	21.4	0.0	423.8		4.0	2.2	2030.3
Public administration	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	1.5	0.0	0.0	0.0	0.0	178.4	4.3	0.0	68.1		0.6	16.0	281.4
Commercial	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7	2.3	0.0	0.0	0.0	0.0	130.9	0.7	0.0	279.1		2.6	0.4	429.9
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.5	0.0	0.0	0.0	0.0	7.1	7.8	0.0	14.4		0.1	0.0	42.5
Miscellaneous	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.8	0.0	0.0	0.0	0.0	38.4	0.0	0.0	0.0		0.0	0.0	49.0
Non energy use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**50.4**	**50.7**	**30.6**	**9.4**	**50.2**	0.0	0.0	**10.4**	0.0	0.0	0.0	**6.4**	0.0	**26.0**	**61.4**	**27.0**	**30.1**	**29.1**	0.0	0.0	0.0	0.0	0.0	0.0	**381.8**

Table A-2: Disaggregated DUKES energy data for analysis: 2010, GCV of fuels, SI units (DECC 2013a, ISSB 2012b)

DUKES 2013 - Disaggregated 2010 PJ [adjusted]	Coal	Coke	Coke breeze	Coke oven gas	Tar and benzole	Blast furnace gas	Other solid fuels	Primary oils	Ethane	Propane	Butane	Other gases	Naphtha	Aviation spirit	Motor spirit	White Spirit & SBP 4	Aviation turbine fuel	Burning oil	DERV	Gas oil	Fuel oils	Lubri-cants	Bitu-men	Petroleum coke	Misc. products	Natural gas(2)	Bioenergy & waste(3)	Primary electricity	MPP electricity	Industry autogen.	Other autogen.	Heat sold	Total
Supply																																	
Indigenous production	480.2	0.0	0.0	0.0	0.0	0.0	0.0	2888.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2394.3	216.8	632.7	0.0			0.0	6612.2
Imports	716.8	1.3	2.1	0.0	0.0	0.0	0.3	2517.7	0.0	8.0	9.8	0.0	32.1	1.1	135.2	8.5	339.2	44.8	348.7	32.1	44.1	27.4	16.7	27.0	5.4	2122.2	80.7	0.0	25.7			0.0	6547.0
Exports	-22.5	-13.0	-1.4	0.0	0.0	0.0	-1.1	-1932.3	0.0	-26.1	-10.0	0.0	-65.5	0.0	-406.3	-1.2	-68.8	-8.8	-96.9	-197.6	-212.3	-19.1	-8.5	-24.5	-44.1	-635.0	-7.9	0.0	36.3	-19.2	-33.2	0.0	-3819.0
Marine bunkers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-71.9	-76.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-148.7
Stock change(4)	192.8	-4.3	-2.5	0.0	0.0	0.0	0.4	-1.7	0.0	-2.3	1.5	0.0	-0.1	0.1	13.8	0.0	5.4	-0.2	2.8	4.3	5.0	-0.8	-4.0	1.9	-0.3	55.0	0.0	0.0	0.0			0.0	266.8
Primary supply	**1367.4**	**-16.0**	**-1.8**	0.0	0.0	0.0	**-0.4**	**3471.9**	0.0	**-20.3**	**1.3**	0.0	**-33.5**	**1.2**	**-257.3**	**7.4**	**275.8**	**35.8**	**254.6**	**-233.0**	**-239.9**	**7.5**	**4.2**	**4.3**	**-39.1**	**3936.4**	**289.6**	**632.7**	**62.0**	**-19.2**	**-33.2**	0.0	**9458.2**
Statistical difference(5)	**4.0**	0.0	**0.0**	**-0.2**	0.0	**-0.3**	**-0.2**	**-1.8**	**15.1**	**11.3**	**10.0**	**-44.7**	**11.1**	**0.2**	**0.9**	**0.1**	**-0.5**	**-0.8**	**-0.3**	**-0.9**	**0.2**	**0.1**	**1.4**	**0.4**	**1.0**	**-9.1**	0.0	0.0	**-1.6**			0.0	**-4.5**
Primary demand	**1363.3**	**-16.0**	**-1.8**	**0.2**	0.0	**0.3**	**-0.2**	**3473.7**	**-15.1**	**-31.7**	**-8.7**	**44.7**	**-44.6**	**1.0**	**-258.2**	**7.3**	**276.3**	**36.6**	**255.0**	**-232.0**	**-240.1**	**7.4**	**2.8**	**3.8**	**-40.1**	**3945.6**	**289.6**	**632.7**	**63.5**	**-19.2**	**-33.2**	0.0	**9462.8**
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
Transfers	0.0	-24.8	24.8	1.0	0.0	0.0	0.0	-111.4	50.9	35.4	16.5	0.0	6.6	0.0	7.8	0.0	-29.9	30.2	-8.2	2.5	-1.0	0.0	0.9	0.0	-0.3	-0.9	0.0	-49.7	49.7			0.0	-0.004
Transformation	**-1283.8**	**42.8**	**-10.5**	**21.0**	**6.1**	**21.5**	**10.4**	**-3362.3**	0.0	**78.9**	**31.5**	**136.2**	**76.3**	0.0	**938.1**	**3.1**	**267.0**	**118.6**	**699.9**	**427.2**	**300.5**	**18.7**	**57.8**	**65.0**	**70.4**	**-1430.3**	**-185.7**	**-583.0**	**1201.6**	**57.4**	**54.2**	**57.0**	**-2094.2**
Electricity generation	-1070.0	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.0	-22.9	0.0	0.0	-6.1	0.0	-1344.9	-184.0	-583.0	1201.6	57.4	54.2	0.0	-1944.7
Major power producers	-1037.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	-17.2	0.0	0.0	-6.1	0.0	-1231.7	-42.4	-583.0	1201.6			0.0	-1718.1
Autogenerators	-32.7	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	-5.7	0.0	0.0	0.0	0.0	-113.2	-141.5	0.0	0.0	57.4	54.2	0.0	-226.7
Industry	-32.6	0.0	0.0	-9.2	0.0	-19.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	0.0	0.0	0.0	0.0	-70.7	-89.8	0.0	0.0	57.4	0.0	0.0	-165.3
Non-industry	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.9	-5.3	0.0	0.0	0.0	0.0	-42.5	-51.7	0.0	0.0	0.0	54.2	0.0	-61.4
Heat generation	-12.1	0.0	0.0	-1.5	0.0	-0.6	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-2.3	0.0	0.0	0.0	0.0	-85.3	-1.7	0.0	0.0			56.966	-47.1
Industry	-9.3	0.0	0.0	-1.5	0.0	-0.6	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	-2.3	0.0	0.0	0.0	0.0	-54.8	-1.3	0.0	0.0	0.0	0.0	38.5	-31.9
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-5.3	0.0	0.0	0.0	0.0	0.0	3.1	-2.5
Non-industry	-2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-30.5	-0.4	0.0	0.0	0.0	0.0	18.4	-15.3
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3362.3	0.0	79.2	31.5	151.9	76.3	0.0	938.1	3.1	267.0	118.6	699.9	430.5	326.0	18.7	57.8	75.3	70.4	0.0	0.0	0.0	0.0			0.0	-17.9
Coke manufacture	-164.9	118.9	1.0	31.8	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-7.1
Iron and steel	-149.5	111.2	0.9	27.7	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.9
Blast furnaces	-29.9	-76.1	-11.5	0.0	0.0	41.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	-76.6
Patent fuel manufacture	-7.0	0.0	0.0	0.0	0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4.3	0.0	0.0	0.0	0.0	0.0			0.0	-0.9
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0	0.0
Energy industry use	**0.1**	0.0	0.0	**15.2**	0.0	**13.2**	0.0	0.0	0.0	0.0	0.0	**126.4**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**22.4**	**22.6**	0.0	0.0	**46.1**	0.0	**248.6**	0.0	0.0	**81.2**	0.0	**11.8**	**3.9**	**591.7**
Electricity generation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.0			0.0	58.0
Oil and gas extraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	0.0	0.0	0.0	0.0	0.0	220.0	0.0	0.0	1.3		0.7	0.0	244.5
Petroleum refineries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.6	0.0	0.0	46.1	0.0	13.8	0.0	0.0	11.8		6.3	3.9	231.0
Coal extraction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	2.2		1.2	0.0	3.9
Coke manufacture	0.0	0.0	0.0	13.9	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2		0.1	0.0	16.9
Iron and steel	0.0	0.0	0.0	14.1	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	17.0
Blast furnaces	0.0	0.0	0.0	1.3	0.0	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	1.1			0.0	15.3
Patent fuel manufacture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Pumped storage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5		1.3	0.0	3.8
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0	0.0	4.1		2.2	0.0	18.3
Losses	0.0	0.0	0.0	**2.2**	0.0	**4.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**67.5**	0.0	0.0	**97.3**			0.0	**171.8**
Final consumption	**79.4**	**2.0**	**12.5**	**4.8**	**6.1**	**3.6**	**10.1**	0.0	**35.8**	**82.6**	**39.3**	**54.5**	**38.3**	**1.0**	**687.6**	**10.4**	**513.5**	**185.5**	**946.7**	**175.2**	**36.9**	**26.0**	**61.4**	**22.7**	**30.1**	**2198.3**	**103.9**	0.0	**1136.3**	**38.2**	**9.2**	**53.0**	**6605.0**
Industry	**55.2**	**1.6**	**12.5**	**4.8**	0.0	**3.6**	0.0	0.0	0.0	**13.7**	**13.3**	**48.8**	0.0	0.0	0.0	0.0	0.0	**68.9**	0.0	**86.5**	**24.3**	0.0	0.0	**10.9**	0.0	**411.9**	**18.8**	0.0	**338.1**	**38.2**	0.0	**34.4**	**1185.4**
Unclassified	0.0	1.4	0.1	0.7	0.0	0.0	0.0	0.0	0.0	13.6	13.3	0.0	0.0	0.0	0.0	0.0	0.0	68.9	0.0	21.0	4.3	0.0	0.0	10.9	0.0	0.1	18.8	0.0	0.0			0.0	153.1
Iron and steel	1.8	0.2	12.4	4.0	0.0	3.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	21.0	0.0	0.0	-0.2	14.0		0.0	57.2
Non-ferrous metals	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	24.2	0.0		0.0	34.3
Mineral products	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	1.6	0.0	0.0	0.0	0.0	55.6	0.0	0.0	26.2	0.0		0.0	123.2
Chemicals	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	5.8	0.0	0.0	0.0	0.0	77.9	0.0	0.0	57.0	9.4		17.4	225.6
Mechanical engineering etc	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.1	0.0	0.0	26.2	1.4		0.0	51.0
Electrical engineering etc	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	24.0	0.0		0.0	35.1
Vehicles	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	31.4	0.0	0.0	19.0	0.0		0.0	55.5
Food, beverages etc	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.8	12.2	0.0	0.0	0.0	0.0	78.6	0.0	0.0	36.9	4.5		0.0	166.3
Textiles, leather etc	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	11.0	0.0		0.0	35.3
Paper, printing etc	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	52.9	0.0	0.0	34.8	4.7		0.1	99.7
Other industries	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.2	0.0	0.0	0.0	0.0	25.0	0.0	0.0	73.1	4.3		16.9	134.8
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	5.8			0.0	14.2
Transport (6)	**0.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**5.2**	0.0	0.0	0.0	**1.0**	**687.6**	0.0	**513.5**	0.0	**946.7**	**34.7**	**7.6**	0.0	0.0	0.0	0.0	0.0	0.0	**51.0**	0.0	**12.8**	0.0	**1.8**	0.0	**2262.5**
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	513.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	514.5
Rail	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8		1.8	0.0	42.8
Road	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0	687.6	0.0	0.0	0.0	946.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	51.0	0.0	0.1		0.0	0.0	1690.6
National navigation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	14.7
Pipelines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Other	**23.6**	**0.3**	0.0	0.0	0.0	0.0	**10.1**	0.0	0.0	**23.2**	**2.2**	0.0	0.0	0.0	0.0	0.0	0.0	**116.6**	0.0	**49.2**	**5.1**	0.0	0.0	0.0	0.0	**1757.4**	**34.1**	0.0	**785.4**	0.0	**7.4**	**18.6**	**2833.1**
Domestic	22.4	0.3	0.0	0.0	0.0	0.0	10.1	0.0	0.0	17.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	116.6	0.0	7.5	0.0	0.0	0.0	0.0	0.0	1402.5	21.4	0.0	423.8		4.0	2.2	2030.3
Public administration	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	1.5	0.0	0.0	0.0	0.0	178.4	4.3	0.0	68.1		0.6	16.0	281.4
Commercial	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7	2.3	0.0	0.0	0.0	0.0	130.9	0.7	0.0	279.1		2.6	0.4	429.9
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.5	0.0	0.0	0.0	0.0	7.1	7.8	0.0	14.4		0.1	0.0	42.5
Miscellaneous	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.8	0.0	0.0	0.0	0.0	38.4	0.0	0.0	0.0		0.0	0.0	49.0
Non energy use	0.0	0.0	0.0	0.0	**6.1**	0.0	0.0	0.0	**35.8**	**40.6**	**23.8**	**5.7**	**38.3**	0.0	0.0	**10.4**	0.0	0.0	0.0	**4.8**	0.0	**26.0**	**61.4**	**11.7**	**30.1**	**29.1**	0.0	0.0	0.0	0.0	0.0	0.0	**323.9**

Table A-3: Disaggregated DUKES energy data for analysis: 2010adjusted, GCV of fuels, SI units (DECC 2007b, 2013a, 2014b, ISSB 2012b, Neelis et al. 2003)

Categories	A	B	C	D	C1	D1	C2	D2
	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)	Direct energy demand, PJ (GCV)
Mining and extraction	248	248	248	248	248	248	248	248
Electricity generation	2003	2003	1837	1833	1837	1833	1837	1833
Heat trading	47	-	-	-	-	-	-	-
Fuel manufacturing	364	366	366	366	252	252	18	18
Other	22	22	22	22	22	22	22	22
Losses	172	172	172	172	165	165	165	165
Demand sectors	6281	6326	6491	6495	6612	6617	6847	6851
Industry	1185	1214	1380	1384	1502	1506	1736	1740
Iron and steel	57	59	84	84	197	197	197	197
Refineries	-	-	-	-	-	-	234	234
Chemicals	226	242	262	267	283	287	283	287
Food and drink	166	169	177	177	177	177	177	177
Pulp and paper	100	102	114	114	59	59	59	59
Cement	123	124	124	124	35	35	35	35
Glass	-	-	-	-	29	29	29	29
Ceramics	-	-	-	-	18	18	18	18
Lime	-	-	-	-	9	9	9	9
Aluminium	-	-	-	-	31	31	31	31
Other industry	360	366	465	465	554	554	554	554
Unclassified	153	153	153	153	110	110	110	110
Transport	2263	2263	2263	2263	2263	2263	2263	2263
Domestic	2030	2030	2030	2030	2030	2030	2030	2030
Services	803	819	819	819	818	818	818	818
NEU	324	324	324	324	324	324	324	324
Industry	196	196	196	196	196	196	237	237
Sub-total	9461	9461	9461	9461	9461	9461	9461	9461
Transfers	0	0	0	0	0	0	0	0
Grand-total	9461	9461	9461	9461	9461	9461	9461	9461

Table A-4: Top-down/bottom-up frameworks of UK energy demand in 2010

Categories	C1	D1	C2	D2
	Direct energy demand, PJ (NCV)	Direct energy demand, PJ (NCV)	Direct energy demand, PJ (NCV)	Direct energy demand, PJ (NCV)
Mining and extraction	225	225	225	225
Electricity generation	1646	1644	1646	1644
Heat trading	-	-	-	-
Fuel manufacturing	237	237	17	17
Other	21	21	21	21
Losses	158	158	158	158
Demand sectors	6210	6212	6430	6432
Industry	1409	1411	1629	1631
Iron and steel	186	186	186	186
Refineries	-	-	219	219
Chemicals	263	264	263	264
Food and drink	165	165	165	165
Pulp and paper	54	54	54	54
Cement	33	33	33	33
Glass	27	27	27	27
Ceramics	16	16	16	16
Lime	8	8	8	8
Aluminium	29	29	29	29
Other industry	524	524	524	524
Unclassified	105	105	105	105
Transport	2147	2147	2147	2147
Domestic	1879	1879	1879	1879
Services	775	775	775	775
NEU	304	304	304	304
Industry	183	183	221	221
Sub-total	8802	8802	8802	8802
Transfers	0	0	0	0
Grand-total	8802	8802	8802	8802

Table A-5: Top-down/bottom-up frameworks of UK energy demand in 2010, NCV of fuels

Categories	C1	D1	C2	D2	C1	D1	C2	D2
	Scope 1 GhG emission, $MtCO_2e$	Scope 1 GhG emission, $MtCO_2e$	Scope 1 GhG emission, $MtCO_2e$	Scope 1 GhG emission, $MtCO_2e$	Scope 1-2/3 GhG emission (credit basis; grid rolling average), $MtCO_2e$	Scope 1-2/3 GhG emission (credit basis; grid rolling average), $MtCO_2e$	Scope 1-2/3 GhG emission (credit basis; grid rolling average), $MtCO_2e$	Scope 1-2/3 GhG emission (credit basis; grid rolling average), $MtCO_2e$
Mining and extraction	13.1	13.1	13.1	13.1	13.9	13.9	13.9	13.9
Electricity generation	162.9	161.3	162.9	161.3	-10.3	-10.3	-10.3	-10.3
Heat trading	-	-	-	-	-	-	-	-
Fuel manufacturing	13.7	13.7	0.0	0.0	17.7	17.7	1.2	1.2
Other	0.6	0.6	0.6	0.6	2.1	2.1	2.1	2.1
Losses	3.5	3.5	3.5	3.5	17.5	17.5	17.5	17.5
Demand sectors	341.4	343.0	355.2	356.8	504.4	504.4	520.8	520.8
Industry	80.4	82.0	94.2	95.7	126.6	126.6	143.1	143.1
Iron and steel	16.3	16.3	16.3	16.3	18.2	18.2	18.2	18.2
Refineries	-	-	13.6	13.6	-	-	16.3	16.3
Chemicals	14.7	16.3	14.7	16.3	21.8	21.8	21.8	21.8
Food and drink	8.7	8.7	8.7	8.7	13.4	13.4	13.4	13.4
Pulp and paper	2.4	2.4	2.4	2.4	3.4	3.4	3.4	3.4
Cement	6.0	6.0	6.0	6.0	6.5	6.5	6.5	6.5
Glass	1.7	1.7	1.7	1.7	2.2	2.2	2.2	2.2
Ceramics	1.0	1.0	1.0	1.0	1.2	1.2	1.2	1.2
Lime	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8
Aluminium	3.0	3.0	3.0	3.0	2.3	2.3	2.3	2.3
Other industry	16.7	16.7	16.8	16.8	47.6	47.6	47.7	47.7
Unclassified	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Transport	152.0	152.0	152.0	152.0	154.1	154.1	154.1	154.1
Domestic	84.9	84.9	84.9	84.9	146.9	146.9	146.9	146.9
Services	24.1	24.1	24.1	24.1	76.7	76.7	76.7	76.7
NEU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other emission (GHGI)	68.8	68.8	68.8	68.8	68.8	68.8	68.8	68.8
Agricultural (non-combustion)	52.9	52.9	52.9	52.9	52.9	52.9	52.9	52.9
Land-use change	-7.3	-7.3	-7.3	-7.3	-7.3	-7.3	-7.3	-7.3
Waste management	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
Sub-total	604.1	604.1	604.1	604.1	614.1	614.1	614.1	614.1
Transfers	-6.2	-6.2	-6.2	-6.2	-16.3	-16.3	-16.3	-16.3
Grand-total	597.8	597.8	597.8	597.8	597.8	597.8	597.8	597.8
Statistics (GHGI)	599.8	599.8	599.8	599.8	599.8	599.8	599.8	599.8

Table A-6: Top-down/bottom-up frameworks of UK GhG emissions in 2010

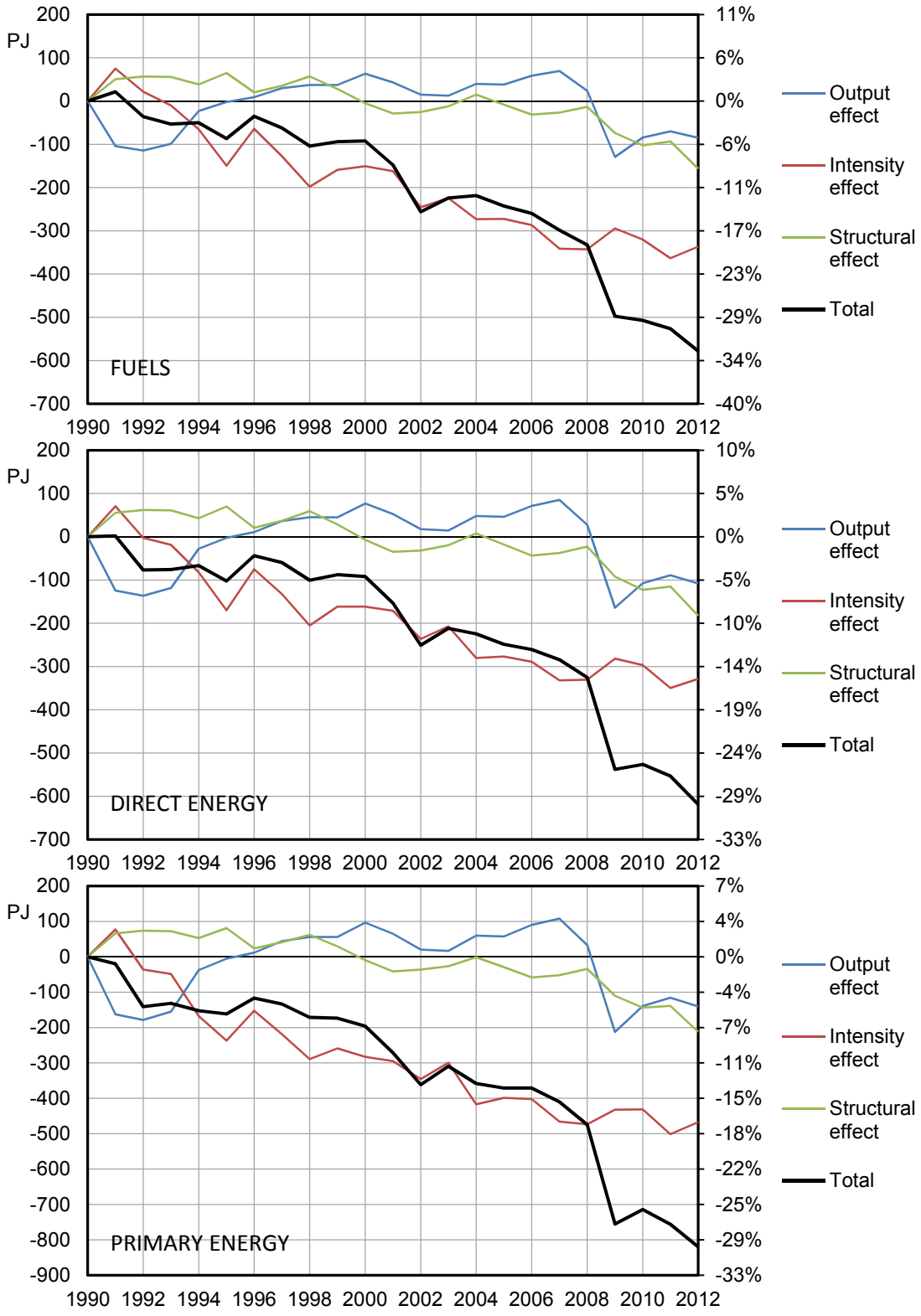

Figure A-3: Energy demand decompositions of UK industry, 1990-2012 (ONS 2014a, 2014b, 2014d)

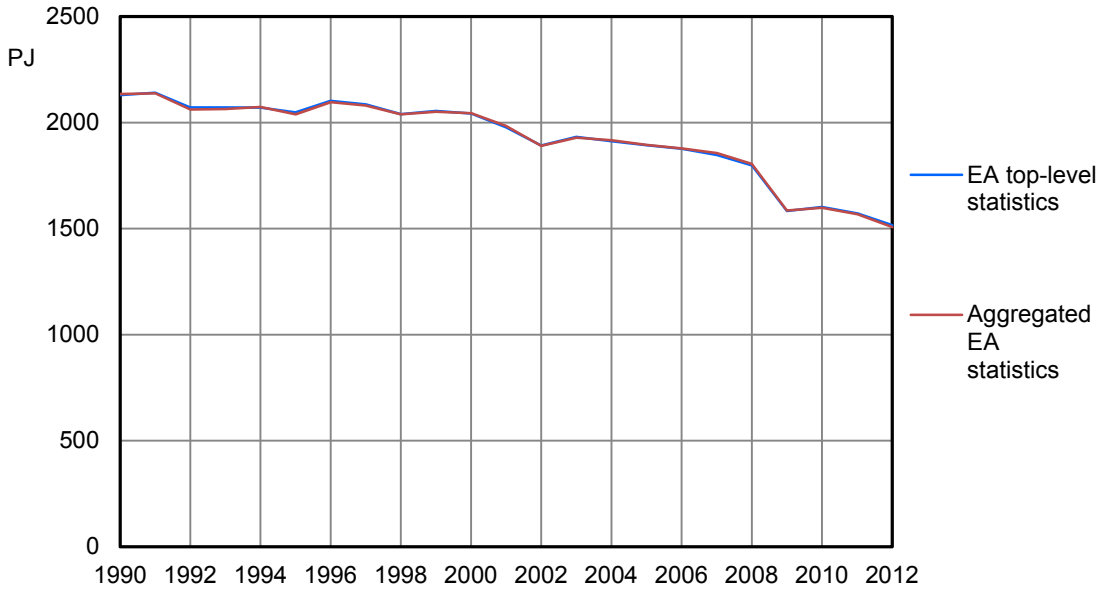

Figure A-4: Comparison of top-down industrial energy demand data with aggregated subsector fuel data with electricity allocation (ONS 2014a, 2014b, 2014d)

A4 Electricity grid energy and emissions intensity projection

In 2010 the primary energy factor for the national grid in terms of direct energy (GCV) requirement, i.e. the simple primary energy factor, was 2.54 for electricity generated and 2.77 after transmission losses (derived from, DECC 2013b, 2013c). The factor depends on the mix of electricity generation technologies. To achieve its targets the Government is attempting to facilitate a 'low carbon technology race' between CCS, renewables and nuclear (HM Government 2011).

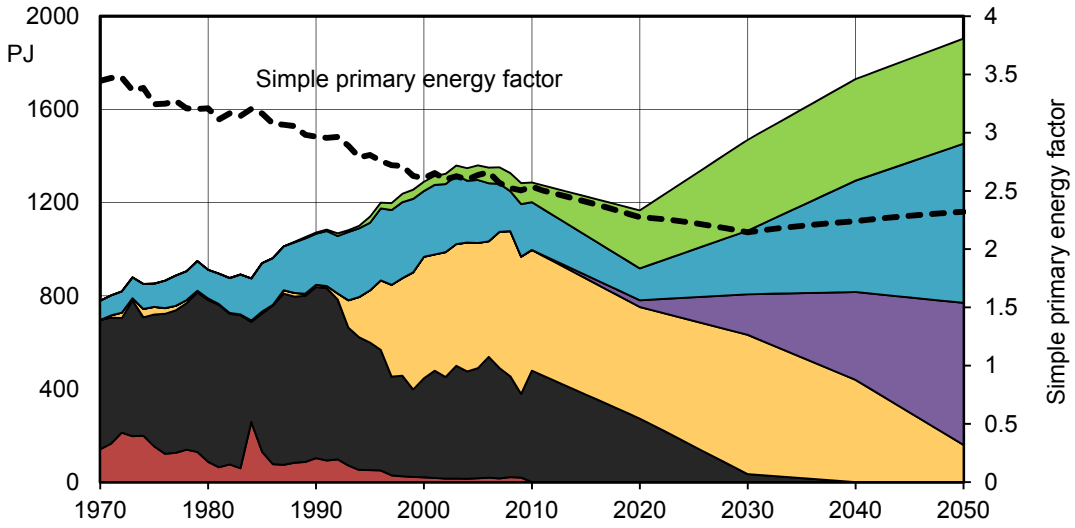

Figure A-5: Historical and projected UK grid electricity generation mix with associated primary energy conversion factor (Barton et al. 2013, DECC 2013b, 2013c)

Figure A-5 shows the long-term historical and projected electricity generation mix over the period 1970-2050 and the resulting simple primary energy factor. The projection is based on the core MARKAL scenario with associated capacity rises and technology capacity factors used in a study by Barton et al. (2013) of the Realising Transition Pathways consortium. An incremental efficiency improvement of 10% is assumed for all sources over the period 2010-2050. The application of CCS may come with an energy penalty of 11-22% for natural gas, 14-25% for coal, and 24-40% for a supercritical pulverised coal plant (Metz et al. 2005). For this simple projection, 25% is assumed for coal and 17% for natural gas. Bio-based generation is assumed as coal. The average factor for CCS is weighted by the share of these technologies as required by the future mix of coal, natural gas, and biomass CCS equipped plant (ibid.).

Generation source	Simple primary energy factor in 2010 (2020 for CCS)	Simple primary energy factor in 2050
Coal	2.9	2.7
Oil	3.2	3.0
Natural gas	2.2	2.0
Nuclear	2.9	2.5
Biomass	4.2	3.7
Wind, wave, tidal, solar	1.0	1.0
CCS 2020 weighted average	4.4	3.2

Table A-7: Primary energy conversion factors in 2010 and projected to 2050

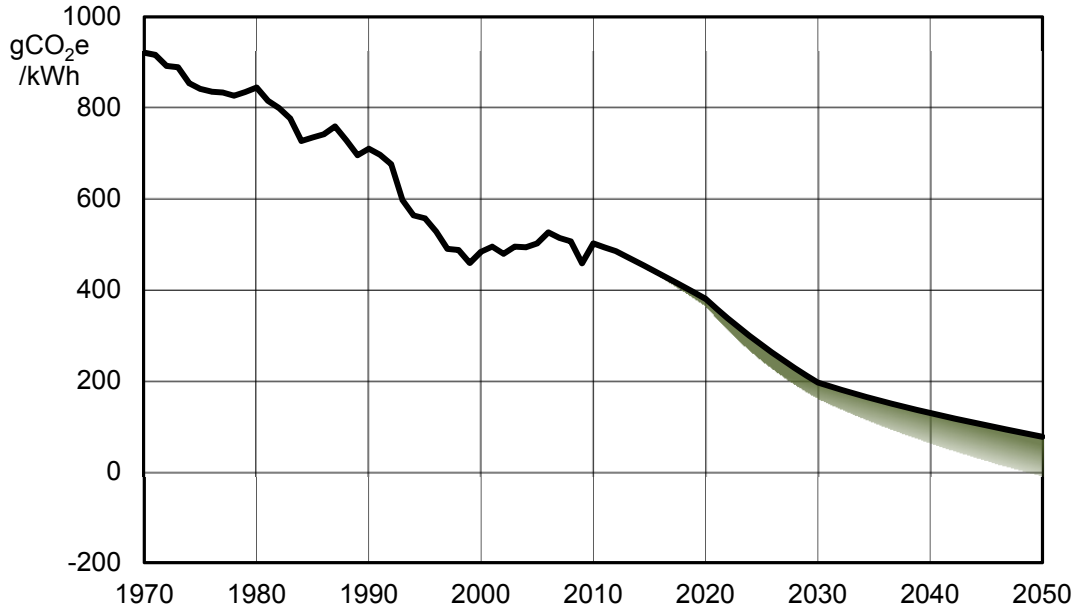

Table A-8: Historical and projected UK grid electricity generation GhG intensity

Simple primary energy factors are displayed in Table A-7. Renewables from wind, wave, tidal and solar have a primary conversion of 1, as they do not deplete natural resources (DECC 2014b). Renewables in the form of biomass, however, is a limited resource and an inefficient fuel for producing electricity compared with conventional fossil fuels.

Figure A-5 shows the historical and projected grid GhG intensity where projected intensity is calculated from the projected generation mix, estimated generation efficiency, and source emissions factors used in DUKES (DECC 2014b). The green area under the curve is the reduction after assuming carbon fixation from biomass, all of which would be stored with CCS, and approximately represents the range of uncertainty in the extent and manor of its utilisation. The higher upper limit on intensity has been adopted for the baseline and is about 50g/kWh in

2050. This equates to an 85% decarbonisation of the 2010 electricity supply system. In the path to this figure, the upper limit of the range 50-200gCO_2/kWh assessed for the UK Electricity Market Reform (EMR) package (DECC 2014i) is reached in 2030.

Historical and projected simple primary energy factors for electricity generated and delivered are tabulated along with scope 2/3 emissions factors in Table A-8. To overcome large year-to-year changes, which may derive from the relative price of coal and natural gas and peak demand fluctuations, the grid rolling average (GRA) is applied. GRA is calculated as the average emissions intensity of the present year and four previous years (AEA 2012). A more aggressive decarbonisation pathway is also introduced here. In this case the lower limit of the 50-200gCO_2/kWh EMR range is reached in 2030 and carbon neutrality is achieved in 2050. The trends for GRA GhG emissions intensity are compared in Figure A-6.

Year	L2 primary energy factor - gross electricity generated (GCV)	L2 primary energy factor - electricity delivered (GCV)	L2 primary energy factor - gross electricity generated (NCV)	L2 primary energy factor - electricity delivered (NCV)	Scope 2/3 GhG emissions factor (grid rolling average) - $kgCO_2e/PJ$	Scope 2/3 GhG emissions factor (grid rolling average) accelerated decarb. - $kgCO_2e/PJ$
1970	3.44	3.78	3.29	3.61	286	286
1971	3.47	3.82	3.31	3.65	287	287
1972	3.47	3.81	3.32	3.64	284	284
1973	3.36	3.68	3.21	3.52	282	282
1974	3.38	3.69	3.23	3.53	279	279
1975	3.24	3.56	3.10	3.40	274	274
1976	3.25	3.55	3.10	3.39	268	268
1977	3.27	3.60	3.13	3.44	264	264
1978	3.21	3.54	3.07	3.38	260	260
1979	3.20	3.53	3.07	3.38	259	259
1980	3.21	3.53	3.07	3.38	260	260
1981	3.11	3.41	2.98	3.27	258	258
1982	3.17	3.48	3.04	3.34	256	256
1983	3.14	3.46	3.02	3.32	252	252
1984	3.20	3.52	3.08	3.38	246	246
1985	3.16	3.49	3.04	3.35	239	239
1986	3.08	3.39	2.96	3.26	234	234
1987	3.07	3.37	2.94	3.23	227	227
1988	3.06	3.35	2.93	3.22	223	223
1989	2.98	3.28	2.87	3.16	218	218
1990	2.97	3.26	2.85	3.13	215	215
1991	2.95	3.26	2.84	3.13	211	211
1992	2.96	3.24	2.85	3.12	205	205
1993	2.89	3.15	2.77	3.02	197	197
1994	2.79	3.12	2.67	2.99	192	192
1995	2.81	3.13	2.68	2.99	181	181
1996	2.76	3.05	2.63	2.90	170	170
1997	2.72	2.99	2.59	2.84	160	160
1998	2.71	3.00	2.58	2.85	154	154
1999	2.63	2.91	2.49	2.75	147	147
2000	2.61	2.89	2.47	2.73	143	143
2001	2.65	2.93	2.51	2.78	142	142
2002	2.60	2.87	2.46	2.71	143	143
2003	2.63	2.90	2.48	2.74	144	144
2004	2.60	2.88	2.45	2.72	147	147
2005	2.64	2.88	2.49	2.72	147	147
2006	2.66	2.91	2.51	2.75	148	148
2007	2.57	2.81	2.41	2.64	150	150
2008	2.52	2.77	2.37	2.60	149	149
2009	2.50	2.76	2.35	2.59	146	146
2010	2.54	2.77	2.39	2.61	145	145
2011	2.50	2.75	2.36	2.59	140	140
2012	2.48	2.74	2.33	2.58	139	137
2013	2.46	2.70	2.31	2.54	138	135
2014	2.43	2.67	2.29	2.51	134	130
2015	2.41	2.64	2.26	2.49	130	124
2016	2.38	2.62	2.24	2.46	126	119
2017	2.36	2.59	2.21	2.43	122	112
2018	2.33	2.56	2.19	2.40	118	106
2019	2.30	2.53	2.16	2.37	115	99
2020	2.27	2.50	2.13	2.34	111	91
2021	2.27	2.49	2.13	2.34	105	82
2022	2.26	2.48	2.12	2.33	99	72
2023	2.25	2.47	2.11	2.32	93	63
2024	2.24	2.46	2.10	2.31	87	54
2025	2.22	2.44	2.09	2.30	81	45
2026	2.21	2.43	2.08	2.28	77	38
2027	2.19	2.41	2.07	2.27	73	31
2028	2.18	2.39	2.05	2.25	69	25
2029	2.16	2.38	2.04	2.24	65	20
2030	2.14	2.36	2.02	2.22	61	16

Table A-9: Estimated L2 PEFs and scope 1/3 GRA EFs of UK grid electricity, 1970-2050

Year	L2 primary energy factor - gross electricity generated (GCV)	L2 primary energy factor - electricity delivered (GCV)	L2 primary energy factor - gross electricity generated (NCV)	L2 primary energy factor - electricity delivered (NCV)	Scope 2/3 GhG emissions factor (grid rolling average) - kgCO2e/PJ	Scope 2/3 GhG emissions factor (grid rolling average): Accelerated - kgCO2e/PJ
2031	2.16	2.37	2.04	2.24	58	14
2032	2.17	2.38	2.05	2.25	55	12
2033	2.18	2.40	2.06	2.27	52	11
2034	2.19	2.41	2.08	2.28	49	9
2035	2.20	2.42	2.09	2.29	46	8
2036	2.21	2.43	2.10	2.31	45	7
2037	2.22	2.44	2.11	2.32	43	6
2038	2.23	2.45	2.12	2.33	41	6
2039	2.23	2.45	2.13	2.34	39	5
2040	2.24	2.46	2.14	2.35	38	4
2041	2.25	2.47	2.15	2.36	36	4
2042	2.26	2.48	2.16	2.38	34	3
2043	2.27	2.49	2.18	2.39	33	3
2044	2.28	2.50	2.19	2.40	31	3
2045	2.29	2.51	2.20	2.41	30	2
2046	2.29	2.52	2.21	2.43	28	2
2047	2.30	2.53	2.22	2.44	27	2
2048	2.31	2.54	2.23	2.45	25	1
2049	2.31	2.54	2.23	2.45	24	1
2050	2.32	2.55	2.24	2.46	22	0

Figure A-cont'd: Estimated L2 PEFs and scope 1/3 GRA EFs of UK grid electricity, 1970-2050

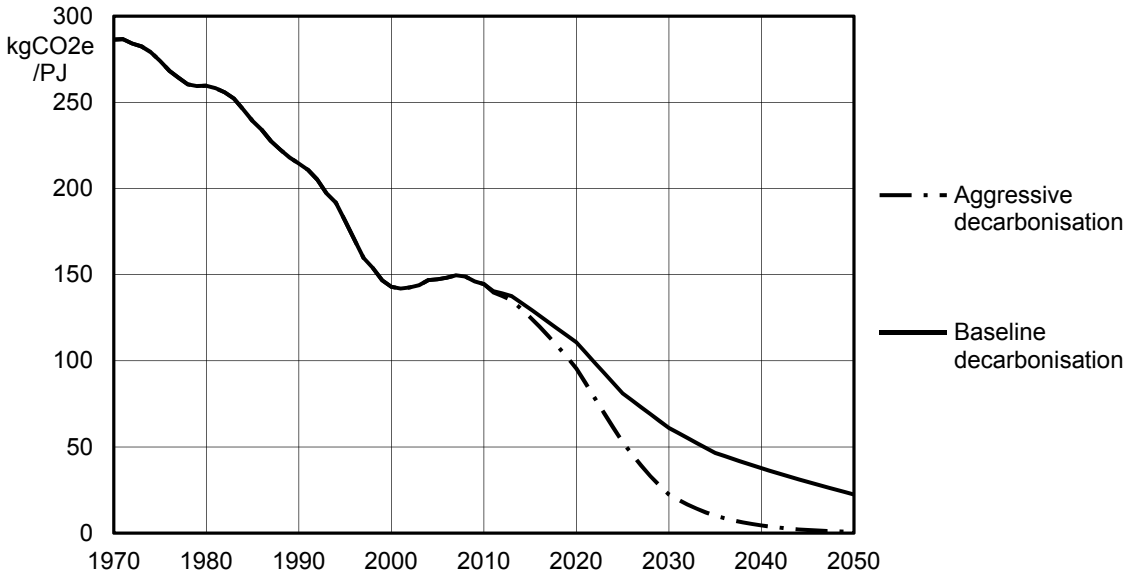

Figure A-6: Comparison of historical and projected GRA GhG emissions factor pathways for delivered grid electricity (scope 2/3), 1970-2050

A5 The iron and steel sector

A5.1 Data

Fuel and electricity flows were first identified at the sector level from ISSB UK iron and steel annual statistics publications (ISSB 2012a). Most plant level flows were obtained either from DUKES (DECC 2014b) or by request from Leach (2013). For some energy flows in steel converters, casting, and rolling plant, however, it was necessary to estimate based on previous surveys (Energy Audit Series 1982, IISI 1996). In some cases the survey data was adjusted for the base year through the identification of subsequent technological investments (Section 4.2).

All heat flows, i.e. steam and condensate, were based on data requested from the ISSB (2013) and aggregated for the system model. Material flows not classified under energy purchases or manufactured energy, e.g. limestone and dolomite, were also based on data from ISSB (ISSB 2012a, Leach 2013).

The raw data obtained for solid and liquid energy flows were in mass units whereas gaseous fuels and steam were in energy units, the former of which was given in gross calorific value (GCV). Thus, mass or volumetric flows of gaseous fuels and steam were back-calculated using the associated energy conversion parameters (section A5.10).

Coal, coke and coke breeze mass data in ISSB statistics are on a wet-basis. In order to account for the variability in moisture content and ensure a more consistent energy conversion, TATA was consulted for dry-basis figures (Leach 2013). In doing so, inconsistencies were uncovered in the data published by DUKES and ISSB. Specifically, the production of coke breeze published in DUKES (DECC 2014b) over the period 2001-2006 appears anomalous compared with the ISSB trend for overall coke production. Though it is recognised that DUKES data covers coke oven activity outside the iron and steel sector, this does not explain the discrepancy. Therefore the data published in DUKES that is used in this thesis has been adjusted accordingly.

A5.1.1 Historic trends

The data presented in all the tables has also been collected or estimated for all years over the period 1973-2011. Past material and energy flows at the sector level, as well as key flows at the coke ovens, is published in the 'brown books' of the ISSB (2013). Past data for blast furnace energy back to 1998 is published in DUKES tables (DECC 2014b) and back to 1990 in the ONS 'Energy Accounts' tables (ONS 2014b). Further to this, data was sourced from past IISI iron and steel statistical energy surveys (IISI 1990, 1996) for major plant over the period 1986-1994. Flows of metal product and blast furnace injectant were also published from these sources over the period 1980-1994. A survey of sector energy and materials in 1978 undertaken for the Energy Audit Series and published jointly by the then Department of Energy and Department of

Industry of the Government (Energy Audit Series 1982) was also consulted. Moreover, material and energy feedstock flows disaggregated to the blast furnace and steel converters were published in the brown books until 1981.

Despite the number of data sources, there were inevitably some gaps in data for the more minor of energy flows and where necessary these were linearly interpolated between sector surveys. The relative insignificance of these data gaps against the key flows of coal, coke, and fuel injectants would suggest that the sector is suitably represented at plant level over the study period.

A5.2 Mass balancing

To achieve mass balance in the tables it was necessary to balance the reactants and products of fuel combustion. Fuel, combustion air, exhaust gas, and solid wastes of combustion are the components of this balance. Combustion air was calculated based on the stoichiometric air plus excess air. Stoichiometric air was calculated per fuel using representative chemical compositions taken from literature (Table A-45 and Table A-46). Total requirement for combustion air was then calculated as the sum of stoichiometric air and excess air. Generic factors for excess air are summarised in Table A-10, from which the mean of the ranges were used for the analysis. Mass of exhaust flow assumes complete combustion and was calculated as equal to the mass of fuel reactant chemicals and combustion air. Waste material mass is assumed as the mass of non-reactant components in the fuel.

Fuel	Excess air factor (mean)
Gas burner	1.1-1.3
Oil burner	1.2-1.5
Coal powder burner	1.1-1.3
Brown coal roast	1.3-1.7
Coke roast - sintering travel grate	1.8

Table A-10: Excess air for combustion in certain processes

In the mass balance tables it is assumed that all steam input, where it is used specifically for heating, exits the system in equal mass. Steam for blast entering the blast furnace is transformed into other products and so output does not cancel with input in this case. Process water is also included in the tables with inputs and outputs balanced. These figures were informed from literature (European Commission 2012b, IEAGHG 2013a) to give an idea of these throughputs but have not been incorporated in the energy analyses. This exclusion was deemed acceptable as the application of process water in the sector is generally limited to closed systems (European Commission 2012b).

Leftover is the mass of energy and material feedstock inputs which were found to approximately match the mass of their products and by-products. The mass balance of the 2007 UK iron and steel sector is given in Table A-176, section A5.11.3, where average error is below 1% and error is not higher than 2%, except for the coke oven where it is 3%. There will be some minor leakages and other material losses that will not have been covered by the flows.

A5.3 Theoretical minimum requirement

Loss may be analysed as the net of process inputs and useful process outputs. The minimum energy, or exergy, is the amount required when all process losses are eliminated. This is equal to the energy content of all useful outputs. However many of the outputs are intermediary products of the system or products utilised within the sector as a whole. Viewed from the sector level, valuable outputs include steel product and by-products that are sold, e.g. blast furnace slag, benzole and tars. These by-products are associated with the practical processes of existing steel production methods and may be omitted from the theoretical minimum.

Substance	Mass
Fe	93.7%
C	4%
Mn	1%
P	0.4%
S	0.05%
Si	0.9%

Table A-11: Chemical composition of pig iron by mass (McGannon 1979, in, Michaelis 1998)

The typical chemical composition of steel is shown in

Table A-11. Simply weighted by mass, i.e. assuming negligible mixture effects, the enthalpy of devaluation and standard chemical exergy of steel is 7.5GJ/t and 6.9GJ/t respectively. These are the presumed absolute minimum requirements for the sector, assuming 100% feedstock from iron ore, which has negligible enthalpy of devaluation and standard chemical exergy. In 2007 the share of scrap in the metallic feedstock of the BOF and EAF was 85% and 2% respectively, and 68% for the sector as a whole. Therefore primary steelmaking has a theoretical minimum energy and exergy requirement of 6.4GJ/t and 5.8GJ/t, equating to sector averages of 5.1GJ/t and 4.6GJ/t respectively. Secondary steelmaking has a negligible theoretical minimum.

A5.4 Process energy analysis

In adopting process energy analysis the wider impact of the steelmaking system can be measured. Specifically, a process analysis carried out at a level 2 regression will embody the inputs and the inputs to the inputs of the processes inside the system boundary. The last published assessment of this type on UK steelmaking was undertaken for the Energy Audit Series (1982) and used data from 1978. Figure A-7 is a process flow diagram using IFIAS conventions of a level 2 process analysis of the BF-BOF route of the 2007 UK liquid steelmaking system. In Figure A-2 the assessment is extended to the level of hot-tolling.

The following points should be considered when reading the diagrams:

- Boxes with bold outlines are level 1 processes and the remaining are level 2
- Energy in the triangles is the enthalpy of combustion (NCV) of fuel demand for the process and in the production of electricity and steam inputs.
- Energy in the rectangles is the direct electricity demand of the process on a heat supplied basis (shown only for level 1 processes).
- PER is the sum of energies inside the triangles and wagons
- GER is the sum of PER and the top-half semi-circles
- NER is the subtraction from GER of the bottom-half semi-circles

PER is the primary energy required to heat or drive the processes of the system (IFIAS 1975). GER includes this energy and the energy of inputs that can be viewed as process feedstock. In reality the distinction between heating and feedstock energy is not always clear cut. For example, coal injectant to the blast furnace both heats the process and provides a source of carbon for chemical reduction. In this assessment all fuels that make up the blast furnace 'fuel rate' (coal, coke and fuel oil) are treated as feedstock.

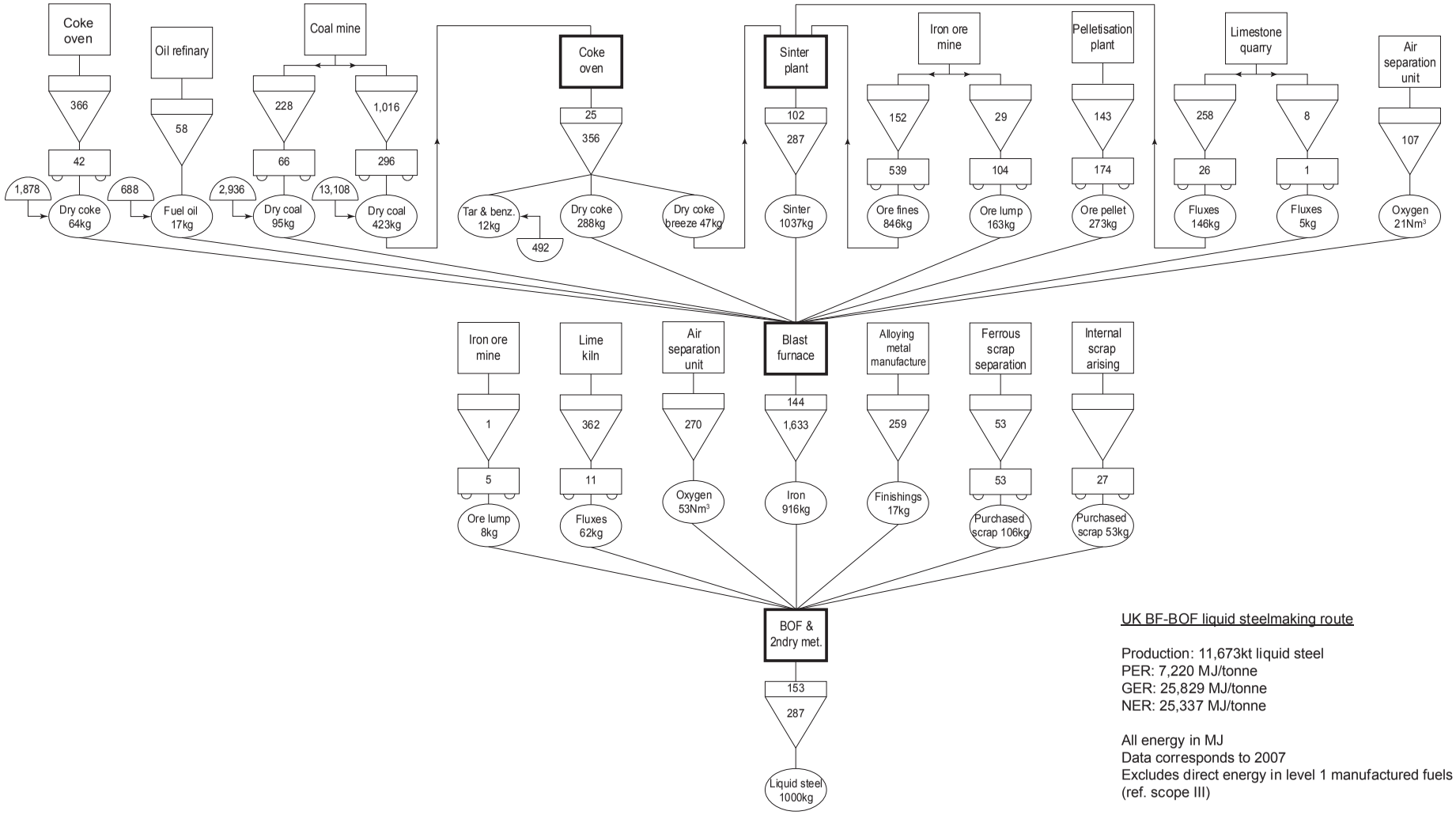

Figure A-7: IFIAS level 2 process energy analysis diagram of the UK BF-BOF liquid steelmaking route in 2007

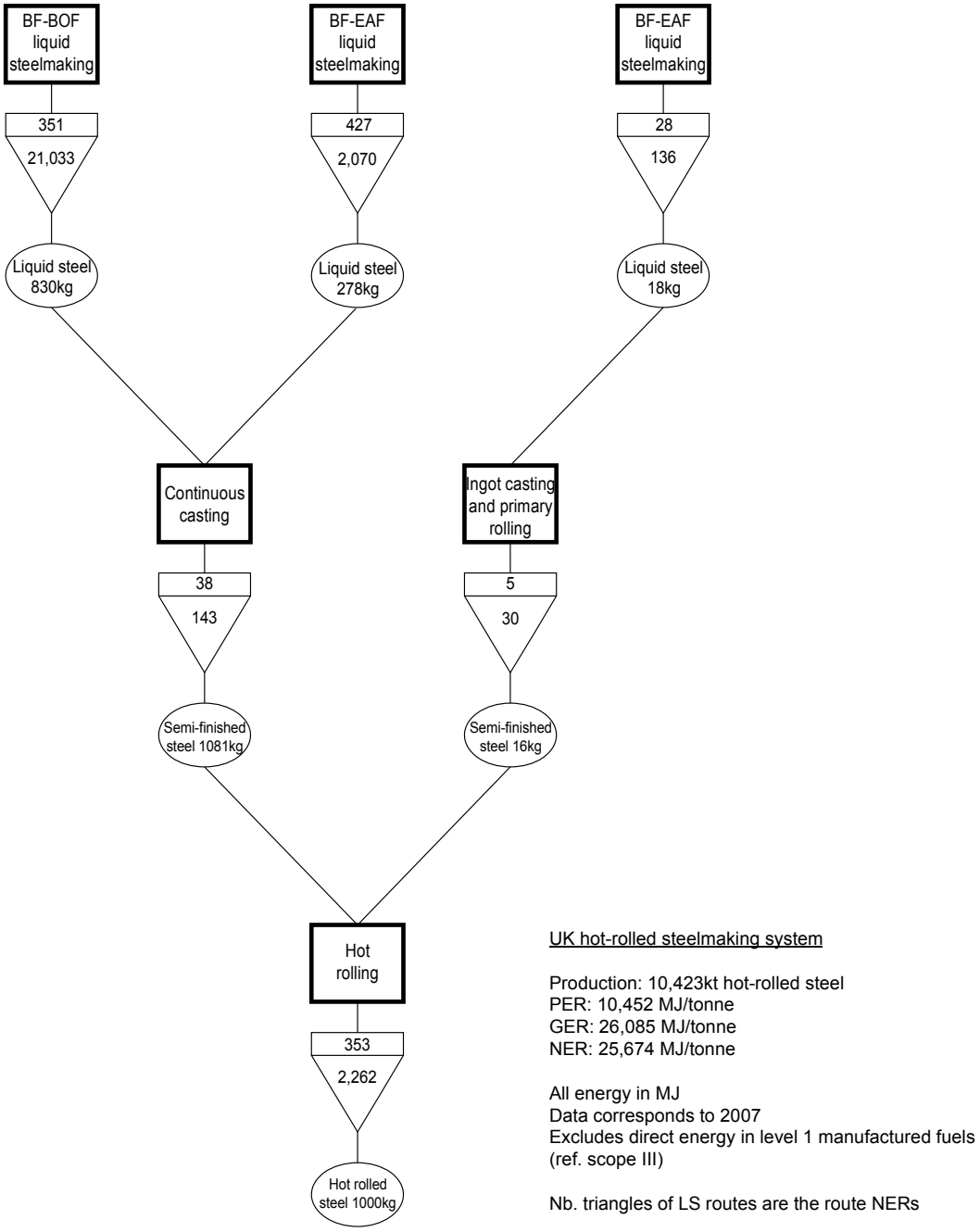

Figure A-8: IFIAS level 2 process energy analysis diagram of the UK hot-rolled steelmaking system in 2007

System	Measure	Scope I	Scope II	Scope III
BF-BOF steelmaking route	PER	10.4	7.5	5.8
	GER	39.7	26.6	25.2
	NER	21.7	26.1	24.7
BF-EAF steelmaking route	PER	7.3	7.3	6.9
	GER	8.1	7.9	7.2
	NER	7.8	7.9	7.2
Steelmaking (average)	PER	9.8	7.5	6.6
	GER	33.1	22.7	21.6
	NER	18.8	22.3	21.2

Table A-12: Measures of energy requirement in GJ/tsfs of steelmaking systems of the iron and steel sector in 2007 at the level of semi-finished steel, represented by different scopes

The iron and steel sector is quite unique in that a significant amount of PER is met by the combustion of process by-product gasses, i.e. coke oven gas, blast furnace gas and basic oxygen furnace gas. These gasses may be combusted to drive processes inside or outside of the steelmaking system boundary, including for the production of steam and electricity also used as process inputs. For simplicity and to avoid double counting, Figure A-7 does not include the energy from by-product gasses where they are produced and used in the level 1 system.

Assessing the system in this way neglects the value by-product gasses surplus to the system. These may displace the consumption of purchased fuels, such as natural gas, to drive other processes within the sector. Specifically this includes processes for the production of steam and electricity which is not demanded by the system and other processes, such as downstream finishing, for which the gas is combusted for direct heating.

Table A-12 summarises the results of a number of different representations. In scope I all energy inputs and outputs of the system are included. In scope II the direct use of internally produced fuels is excluded (as shown in Figure A-7). In scope III all internally produced fuels, including indirect use as fuel for the production of steam and electricity input, are excluded.

System	Measure	Scope I	Scope II
Integrated steelworks site	PER	16.7	9.1
	GER	47.1	28.9
	NER	28.4	28.4
EAF steelworks site	PER	11.5	11.5
	GER	11.8	11.8
	NER	11.8	11.8
Iron and steel sector	PER	16.1	9.6
	GER	39.6	25.3
	NER	24.9	24.9

Table A-13: Measures of energy requirement in GJ/tcs of sites of the iron and steel sector in 2007 at the level of semi-finished steel, represented by different scopes

Table A-13 presents the results to analysis of the integrated and EAF steelworks sites[*]. As no by-product gas, electricity or steam is exported from the system, there is no need to adjust for indirect returns as calculated for scope III. Scope I and II also have equal NER because of this fact.

A5.5 Economic data and assumptions

Most of the economic data and assumptions, in particular those associated with the base integrated site and TGR-BF retrofitted site, were taken from a recent techno-economic study, conducted under the IEAGHG implementing agreement (IEAGHG 2013a), on a European integrated steelworks.

The production life of a site and its process plant is 25 years. To reach this age the blast furnace, TGR-BF and HIsarna smelt reduction furnace are assumed to require relining in the 15th year. Relining would disrupt production in that year, however production is assumed to be unaffected. This simplification was found to have a negligible effect on the results. Initial capital investment for a site is paid over five years with an annual schedule of 10% in the first year, then 35%, 30%, 20% and 5% in the four years that follow. Production begins on the fourth year of this schedule and thus the project life is 28 years.

[*] The standard unit of output representing the manufacturing site is crude steel which is slightly different to semi-finished steel due to the presence of ingot casting at the EAF site. In 2007 the EAF site produced 2,998ktsfs and 3028ktcs (or 3017ktcs excluding liquid steel for castings). In contrast the integrated site produced 11,362ktcs and the same amount in semi-finished steel as all production was continuously cast.

Production from a Greenfield site is 'ramped up' over a few years, or the commissioning period, before reaching full capacity. Production is 50% of capacity in the first year, 75% in the second, 90% in the third, and 100% from the fourth. Though this initial shortfall is incorporated into the calculation for annualised production cost, it is assumed not to translate to a fall in production at the sector level.

The capital expenditure required for new process plant can be significantly different to the cost associated with extending the life of existing plant through major refurbishment or rebuild. This difference can vary considerably depending on the plant and its circumstances. In the recent 2050 roadmap study by BCG (2013) a renewal cost of 15% of the Greenfield investment for coke ovens was assumed, 30% for the sinter plant, and 50% for blast furnaces and basic oxygen furnaces. The assessment here assumes these rates and applies a figure of 50% for the electric arc furnace, casting, rolling, finishing, power plant and boilers. In the specific case of the BAT EAF, a renewal cost factor of 75% is applied to the figure which includes the new furnace plus all other existing equipment of the melt shop (i.e. secondary metallurgy).

For any Greenfield site it is necessary to build up a working capital. Working capital includes the value of raw materials (e.g. iron ores and purchased scrap), semi-finished and hot-rolled steel stored in the stockyard and balance of trade between debtors and creditors (IEAGHG 2013a). For trade debtors only the sale value of steel product is considered whilst for trade creditors the value of materials excluding raw materials is considered. The elapsed time for material storage and balance of trade is based on standard industry practice: 63 days for raw material stock, 5 days for semi-finished steel product, 15 days for hot-rolled steel product, 15 days for trade debtors, and 30 days for trade creditors (ibid.). If the site is not Greenfield then the full working capital is assumed to have already been established.

In calculating production cost a discount rate of 10% was applied. Inflation has been excluded from the assessment. Depreciation of plant equipment and site decommissioning costs are also excluded.

Currency is 2010 GBP as 2010 is the base year for the usable energy database project (UKERC 2013). The IEAGHG (2003) study from which much of the cost data derives uses 2010 conversion rates for USD and EUR currency of 1.55 and 1.34 respectively.

Plant	Output	CAPEX, £m/output	Uncertainty range
Coke ovens	t dry coke	202	20%
Sinter plant	t sinter	42	20%
Blast furnace	t hot metal	137	20%
BOF w/ 2nd met.	t liquid steel	89	20%
EAF w/ 2nd met.	t liquid steel	125	20%
EAF w/ 2nd met. (BAT)	t liquid steel	150	33%
Continuous casting machines	t semi-finished steel	39	20%
Ingot casting	t semi-finished steel	97	40%
Thin slab casting	t hot-rolled steel	97	40%
Hot rolling w/ reheat furnace	t hot-rolled steel	97	20%
Cold rolling and coating	t finished steel	97	40%
Boilers	GWh steam	36	20%
Condenser turbine gen.	GWh electricity	150	40%
NGCC/syngas turbine gen.	GWh electricity	150	40%
ASU	Nm^3 oxygen	39	20%
TGR blast furnace	t hot metal	134	20%
HIsarna w/ coal pyrolysis	t hot metal	200	50%
MIDREX w/ gas reformer	t direct reduced iron	350	33%
ULCORED w/ POX	t direct reduced iron	350	50%
ULCORED w/ shell gasifier	t direct reduced iron	350	50%
ULCORED w/ FB gasifier	t direct reduced iron	350	50%
ULCOWIN unit	t electrowinned iron	350	66%

Table A-14: CAPEX and associated uncertainty range for baseline and potential future process plant of the UK iron and steel sector (IEA ETSAP 2010, IEAGHG 2013a)

Equipment	Plant	Output	CAPEX, £m/output	Uncertainty range
Coke dry quenching equip.	Coke oven	t dry coke	20	33%
Exhaust gas recirculation	Sinter plant	t sinter	4	33%
Cooler heat recovery	Sinter plant	t sinter	3	33%
Increased coke	Blast furnace	t hot metal	4	33%
Slag heat recovery	Blast furnace	t hot metal	5	50%
BOFG chem./sens. recovery	BOF	t liquid steel	30	33%
MEA capture	Various	tCO_2	101	33%
MDEA capture	Various	tCO_2	123	33%
VPSA capture	Various	tCO_2	82	33%

Table A-15: CAPEX and associated uncertainty range for baseline and potential future process equipment of the UK iron and steel sector (Ho et al. 2013, IEAGHG 2013a, NEDO 2008, US EPA 2012)

A5.5.1 Capital expenditure

The assumed capital expenditure (CAPEX) of each major process plant is summarised in Table A-14. For each plant a range has been assigned to reflect uncertainty either indicated in literature or estimated based on the technology's stage of development. The CAPEX of retrofit energy efficiency and carbon abatement equipment is summarised in Table A-15. The BAT sites include all separately identified additional equipment plus other minor equipment incorporated in the AllTech process plant detailed in the IISI (1998) technical report on iron and steel energy. To account for these further measures a conservatively applied factor of 1.5 is applied to the collective cost of the improvement technology portfolio (detailed in section 4.4.5.1). This is based on the baseline site adopting the portfolio achieving two thirds of the emission abatement achieved by the BAT site.

Other plant and equipment costs include the cost of raw material handling and spare parts, auxiliary equipment, utilities and balance of plant systems. In the IEAGHG (2013a) study, the combined cost of these is £119m, or 20% of the site's major plant and equipment CAPEX total. For simplicity this fraction is applied to all sites.

Contingency is applied in investment calculations to cover possible cost overruns and estimating errors. A standard contingency cost factor of 5% is assigned to all plant and equipment except for capture technology to which the applied factor is 15% (IEAGHG 2013a). CAPEX relating to the Greenfield site include site development and preparation, construction of buildings and infrastructure, and project engineering. The combined cost of these is 112 £/tcs in (ibid.) and is applied to all Greenfield sites with an uncertainty range of +/-50%.

A5.5.2 Operational expenditure

Operational expenditure (OPEX) is the annual expenditure required to cover the ordinary running of production. Fixed OPEX includes the cost of maintenance, labour and miscellaneous expenses such as on-site haulage or disposal and landfill costs.

Plant/equipment	Fixed OPEX, % of CAPEX
Coke oven	5%
Sinter plant	5%
Blast furnace (exc. relining)	4%
BOF	5%
EAF	5%
Continuous casting machine	8%
Thin slab caster	8%
Hot rolling, inc. reheat furnace	8%
Cold rolling and coating	8%
Heat and power plant	4%
ASU	2.5%
CO_2 capture and compression plant	2.5%
Other (default)	5%

Table A-16: Fixed OPEX of key process plant and equipment for the UK iron and steel sector (IEAGHG 2013a)

Maintenance costs are linked to the installed plant and equipment and are shown in Table A-16 as a proportion of plant CAPEX. Labour and miscellaneous costs are linked to the type of site and have been estimated based on the approximate scale of operations assumed for each of the main site types. Labour and miscellaneous costs at the integrated site amount to 70m£/yr. The cost at the HIsarna site is assumed to be 75% of this, DRI and electrolysis sites are assigned 66%, and the EAF site is 50%.

Variable OPEX includes all material and energy purchases. This can also include revenue from the sale of by-products including slags, tars and benzole. The price of these commodities can be expected to change over time. Table A-17 summarises the cost of key resource flows and suggest annual growth rates based on the rates used in a roadmap study by the Joint Research Centre of the European Commission (2012c). Biomass cost is the average of costs for wood chips, pellets, and agricultural residues used in a prospective study for biomass based DRI production (Buergler

and Donato 2008) and is kept constant. The cost of charcoal is assumed as the generic cost of biomass per unit of energy as estimated here.

Resource flow	Units	2010 price	2050 price	Annual growth rate
Coking coal	£/t (£/GJ)	119 (4.2)	225 (8)	1.6%
Coal	£/t (£/GJ)	65 (2.3)	124 (4.4)	1.6%
Natural gas	p/kWh (£/GJ)	1.64 (5.1)	3.6 (11.2)	2%
Electricity	p/kWh (£/GJ)	5.96 (16.6)	8.2 (22.8)	0.8%
Biomass	£/t (£/GJ)	236 (18.6)	236 (18.6)	0%
Oxygen	p/Nm^3	6	8	0.8%
Iron ore	£/t	57	91	1.2%
Scrap	£/t	147	237	1.2%
Finishings	£/t	1,132	1,824	1.2%

Table A-17: Suggested prices and price increases of key resources of the UK iron and steel sector

A5.6 Techno-economic roadmap projection model (continued)

This section is an extension of section 4.5.2. More detail on the account of key variables is given and roadmap designs are shown. Other model outputs also shown.

Figure A-9 is a screenshot of the control interface for selected variables. The yellow and orange fields are the user input fields. The orange fields indicate that the variable will change the emission of GhGs targeted for capture. At many sites the CO_2 from fuels combusted for onsite steam and electricity are captured. Some of the generated steam and electricity is demanded by the equipment that separates CO_2 from the exhaust stream of the generation plant. Process sizing is therefore mutually dependent. The model iterates the size automatically but in doing so may compromise the speed at which the software can run. Therefore a separate version of the model has been created in which the iterations are to be made by manually copying and pasting the cell values of captured CO_2 for all relevant plant in a single block. Five iterations are sufficient for reducing error to within 1% in all cases. An orange field indicates that its edit must be accompanied by this manual procedure.

Illustrative and optimised roadmaps constructed in the model for the assessment in sections 4.5.5 and 4.5.6 are shown in Figure A-10 and Figure A-11 respectively.

Variable	Input	Suggested	Other OPEX suggested	Unit /choice	Notes
Variable OPEX flows					
CO_2 trading price	0	0	100	£ per tonne	
CO_2 sale price	0	0	50	£ per tonne	
Iron ore price	56.57	56.57	91.15	£ per tonne	
Finishings	1,132	1,132	1,824	£ per tonne	
Coking coal price	119	119	225	£ per tonne	
Coal price	65.46	65.46	124	£ per tonne	
Scrap price	147	147	237	£ per tonne	
Natural gas price	1.64	1.64	3.63	pence per kWh	
Biomass price	236	236	236	£ per tonne	
Charcoal price	106	106	106	£ per tonne	
Electricity price	5.96	5.96	8.20	pence per kWh	
O2 price	0.06			£ per Nm3	Linked to electricity
Price only tradable CO_2?	Y	Y		Y/N	
Include elec in CO_2 price?	N	N		Y/N	
Flat price	N	N		Y/N	
Other techno-economic variables					
Load factor	90%	90%		%	Nameplate capacity load factor
Global discount rate?	Y	Y		Y/N	
Discount rate	10%	10%		%	
Global technology lifespan?	Y	Y		Y/N	
Lifespan	25	25		Years (15-40)	
Ramp-up capacity?	Y	Y		Y/N	
Ramp extent	100%	100%		%	
Greenfield only?	Y	Y		Y/N	
Retrofit/Greenfield plant cost					
Coke oven	15%	15%		%	
Sinter plant	30%	30%		%	
Blast furnace	50%	50%		%	
Basic oxygen furnace	50%	50%		%	
Electric arc furnace	50%	50%		%	
Other plant	50%	50%		%	
Additional technical variables					
Updated 2007 baseline (2007u)?	Y	Y		Y/N	
33% thin-slab casting	100%	100%		% (0-100)	
Slag heat recovery?	Y	Y		Y/N	
TGR-BF coke rate	259	259		187-259kg/thm	Minimum total fuel rate, 367kg/thm
TGR-BF coal injection rate	152	152		152-180kg/thm	Minimum total fuel rate, 367kg/thm
DRI scrap level	40%	40%		% (30-70)	
ULCOWIN scrap level	16%	16%		% (16-70)	
Biomass C-fixation	Y	Y		Y/N	
HISARNA w/ sep. - CO_2 storage?	Y	Y		Y/N	
Bio-HISARNA?	N	N		Y/N	
% charcoal subs.	100%			% of fuel energy input	
Effective CCU emissions abatement	0%	67%		% of capture (0-100)	
Equipment capture efficiency					
RETROFIT	85%	85%		%	
TGR-BF	90%	90%		%	
HISARNA	90%	90%		%	
MIDREX	85%	85%		%	
ULCORED	90%	90%		%	
Boiler/generator efficiency					
Coal syng. boiler efficiency	80%	80%		%	
Bio.syng. boiler efficiency	80%	80%		%	
Coal.syng. turbine efficiency	45%	45%		%	
Bio.syng. turbine efficiency	45%	45%		%	

Figure A-9: Screenshot of iron and steel techno-economic projection model variable control interface

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	BAT uptake	35% BOF scrap	Int.wks (Base)	EAF wks (Base)	EAF gnf.wks	Int.wks (CCS)	TGR-BF wks (CCU)	TGR-BF wks (CCS)	Hlsarna wks w/o sep.	Hlsarna wks (CCU)	MIDREX wks	MIDREX wks (CCS)	ULCORED wks, NG (CCS)	ULCORED wks, coal (CCS)	ULCORED wks, coal w/exs syng. (CCS)	ULCORED wks, bio (CCS)	ULCORED wks, bio w/exs syng. (CCS)	ULCOWIN wks w/o autogen.
RA		Reasonable action																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	64%	16%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	37%	16%	7%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	26%	16%	11%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	14%	16%	14%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCU		Reasonable action with CCU and CO2 sale								*(CCU)*								
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	64%	16%	0%	0%	14%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	37%	16%	7%	0%	28%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	26%	16%	11%	0%	28%	0%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	14%	16%	14%	0%	28%	0%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS		Reasonable action with CCS								*(CCS)*								
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	64%	16%	0%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	37%	16%	7%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	26%	16%	11%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	14%	16%	14%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%
RA2-CCS		Reasonable action with CCS - optimised structure for capture								*(CCS)*								
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	58%	16%	6%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	33%	16%	11%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	22%	16%	15%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%
GT		Gas process transition																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	81%	16%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	68%	16%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	58%	16%	0%	0%	0%	0%	0%	0%	26%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	48%	16%	0%	0%	0%	0%	0%	0%	36%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	38%	16%	0%	0%	0%	0%	0%	0%	46%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	28%	16%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%	0%	0%	0%	0%
GT-CCS		Gas process transition with CCS																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%
2035	67%	20%	68%	16%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%	0%
2040	67%	25%	58%	16%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%	0%	0%	0%
2045	67%	33%	45%	16%	0%	0%	0%	0%	0%	0%	0%	0%	39%	0%	0%	0%	0%	0%
2050	67%	41%	28%	16%	0%	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%	0%	0%
RT		Radical process transition																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	77%	16%	4%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	62%	16%	6%	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	52%	16%	8%	0%	0%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	36%	16%	11%	0%	0%	0%	0%	0%	32%	0%	0%	0%	0%	0%	0%	5%
2045	67%	33%	20%	16%	14%	0%	0%	0%	0%	0%	40%	0%	0%	0%	0%	0%	0%	10%
2050	67%	41%	0%	16%	17%	0%	0%	0%	0%	0%	47%	0%	0%	0%	0%	0%	0%	20%
ET		Existing process transition																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	81%	16%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	78%	16%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	75%	16%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	72%	16%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	67%	16%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	62%	16%	22%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	57%	16%	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BT-CCS		Biomass process transition with CCS																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%
2035	67%	20%	68%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%
2040	67%	25%	58%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%
2045	67%	33%	45%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	39%	0%	0%
2050	67%	41%	28%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%
BT2-CCS		Biomass process transition with CCS - maximum biomass																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%
2035	67%	20%	68%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%
2040	67%	25%	58%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%
2045	67%	33%	45%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	39%	0%
2050	67%	41%	28%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	56%	0%
CT-CCS		Coal process transition with CCS																
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	78%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%
2035	67%	20%	68%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%	0%
2040	67%	25%	58%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%	0%	0%
2045	67%	33%	45%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	39%	0%	0%	0%	0%
2050	67%	41%	28%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%	0%

Figure A-10: Screenshot of techno-economic projection model illustrative roadmap designs

				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	BAT uptake	35% BOF scrap	Int.wks (Base)	EAF wks (Base)	EAF gnf.wks	Int.wks (CCS)	TGR-BF wks (CCU)	TGR-BF wks (CCS)	HIsarna wks w/o sep.	HIsarna wks (CCU)	MIDREX wks	MIDREX wks (CCS)	ULCORED wks, NG (CCS)	ULCORED wks, coal (CCS)	ULCORED wks, coal w/exs syng. (CCS)	ULCORED wks, bio (CCS)	ULCORED wks, bio w/exs syng. (CCS)	ULCOWIN wks w/o autogen.
RA2.1-CCS	Reasonable action with CCS: Accelarated process transition; 100% charcoal HIsarna																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	80%	16%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	72%	16%	6%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	52%	16%	12%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	29%	16%	15%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	19%	16%	18%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA2.2-CCS	Reasonable action with CCS - Accelarated process transition; 85% charcoal HIsarna																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	79%	16%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	70%	16%	8%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	50%	16%	13%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	28%	16%	16%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	19%	16%	18%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA2.3-CCS	Reasonable action with CCS - Accelarated process transition; 100% charcoal HIsarna for mean target; 75% for min target																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	78%	16%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	69%	16%	9%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	49%	16%	15%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	27%	16%	17%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	18%	16%	19%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA3-CCS	Reasonable action with CCS - Accelarated process transition; Increased HIsarna integration; 95% charcoal HIsarna																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	83%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	79%	16%	2%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	60%	16%	8%	0%	0%	7%	0%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	40%	16%	12%	0%	0%	14%	0%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	21%	16%	16%	0%	0%	14%	0%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	14%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA4-CCS	Reasonable action with CCS - Accelarated process transition; Highly increased HIsarna integration; 75-100% charcoal HIsarna for target range																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	64%	16%	8%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	47%	16%	13%	0%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	25%	16%	17%	0%	0%	0%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	0%	16%	20%	0%	0%	0%	0%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA4.1-CCS	Reasonable action with CCS - Highly increased HIsarna integration; 100% charcoal HIsarna																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	83%	16%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	67%	16%	5%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	53%	16%	7%	0%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	34%	16%	8%	0%	0%	0%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	10%	16%	10%	0%	0%	0%	0%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RT2	Radical process transition - for min target																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	77%	16%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	67%	16%	12%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	60%	16%	16%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	50%	16%	17%	0%	0%	0%	0%	0%	17%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	38%	16%	17%	0%	0%	0%	0%	0%	21%	0%	0%	0%	0%	0%	0%	0%	8%
2045	67%	33%	25%	16%	17%	0%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%	17%
2050	67%	41%	0%	16%	17%	0%	0%	0%	0%	0%	33%	0%	0%	0%	0%	0%	0%	0%	33%
RT3	Radical process transition - for min target; accelarated ULCOWIN																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	77%	16%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	67%	16%	12%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	58%	16%	16%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	55%	16%	19%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	43%	16%	21%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	10%
2045	67%	33%	27%	16%	22%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	25%
2050	67%	41%	0%	16%	24%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	50%
RET	Radical existing process transition - Total recycling																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	78%	16%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	72%	16%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	66%	16%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	20%	52%	16%	32%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	25%	38%	16%	46%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	33%	24%	16%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	41%	0%	16%	84%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure A-11: Screenshot of techno-economic projection model optimised roadmap designs

				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	BAT uptake	35% BOF scrap	Int.wks (Base)	EAF wks (Base)	EAF gnf.wks	Int.wks (CCS)	TGR-BF wks (CCU)	TGR-BF wks (CCS)	HIsarna wks w/o sep.	HIsarna wks (CCU)	MIDREX wks	MIDREX wks (CCS)	ULCORED wks, NG (CCS)	ULCORED wks, coal (CCS)	ULCORED wks, coal w/exs syng. (CCS)	ULCORED wks, bio (CCS)	ULCORED wks, bio w/exs syng. (CCS)	ULCOWIN wks w/o autogen.
RA4-CCU	Reasonable action with CCU - Accelarated process transition; Highly increased HIsarna integration; 100% charcoal HIsarna; 67% CCU abatement; for mean target																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	83%	16%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	79%	16%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	60%	16%	12%	0%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	45%	16%	15%	0%	0%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	24%	16%	18%	0%	0%	0%	0%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	0%	16%	20%	0%	0%	0%	0%	0%	64%	0%	0%	0%	0%	0%	0%	0%	0%
RA4.1-CCU	Reasonable action with CCU - Accelarated process transition; Highly increased HIsarna integration; 100% charcoal HIsarna; 67% CCU abatement																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	83%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	64%	16%	8%	0%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	47%	16%	13%	0%	0%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	25%	16%	17%	0%	0%	0%	0%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	0%	16%	20%	0%	0%	0%	0%	0%	64%	0%	0%	0%	0%	0%	0%	0%	0%
RA2.1-CCU	Reasonable action with CCU - Accelarated process transition; 100% charcoal HIsarna; 67% CCU abatement																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	81%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	78%	16%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	69%	16%	9%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	49%	16%	15%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	27%	16%	17%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	18%	16%	19%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA3-CCU	Reasonable action with CCS - Accelerated process transtion; Increased HIsarna integration; 100% charcoal HIsarna; 67% CCU abatement																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	81%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	75%	16%	5%	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	56%	16%	12%	0%	0%	7%	0%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	36%	16%	16%	0%	0%	14%	0%	18%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	19%	16%	18%	0%	0%	14%	0%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	14%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA4	Reasonable action - Accelarated process transition; Highly increased HIsarna integration; 100% charcoal HIsarna; no CCS; for higher cap																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	83%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	63%	16%	9%	0%	0%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	47%	16%	13%	0%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	25%	16%	17%	0%	0%	0%	42%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	0%	16%	20%	0%	0%	0%	64%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA2.4-CCS	Reasonable action - Accelarated process transition; 0% charcoal HIsarna; for higher cap																		
2015	10%	0%	84%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	25%	5%	83%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	40%	10%	82%	16%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	55%	15%	73%	16%	4%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	67%	0%	53%	16%	11%	0%	0%	14%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	67%	0%	30%	16%	14%	0%	0%	28%	0%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	67%	0%	20%	16%	17%	0%	0%	28%	0%	19%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	67%	0%	8%	16%	20%	0%	0%	28%	0%	28%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure A- cont'd: Screenshot of techno-economic projection model optimised roadmap designs

A5.6.1 Other model outputs

The following outputs supplement the assessment outputs of chapter 4.

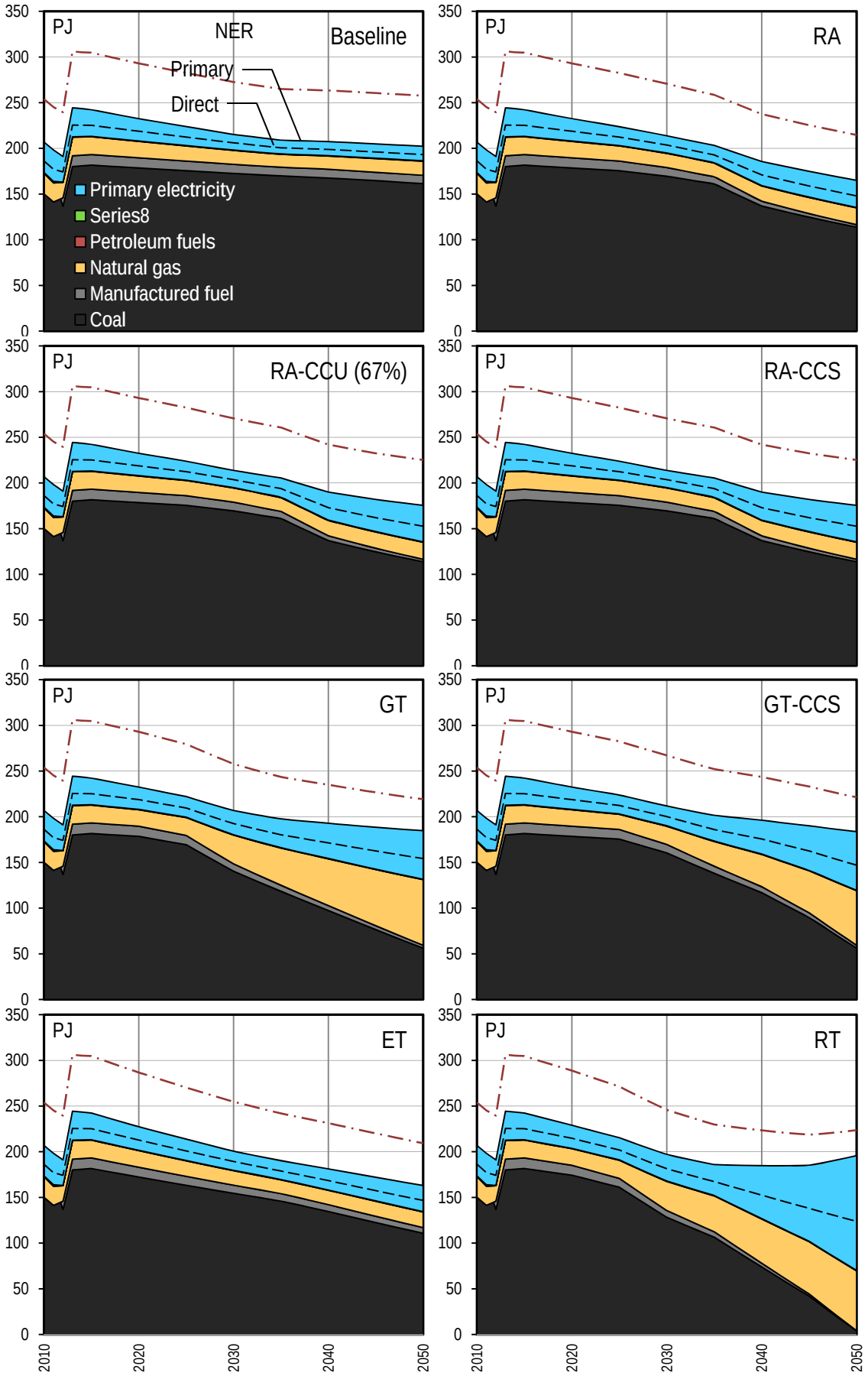

Figure A-12: Energy splits of illustrative technology roadmaps of the UK iron and steel sector

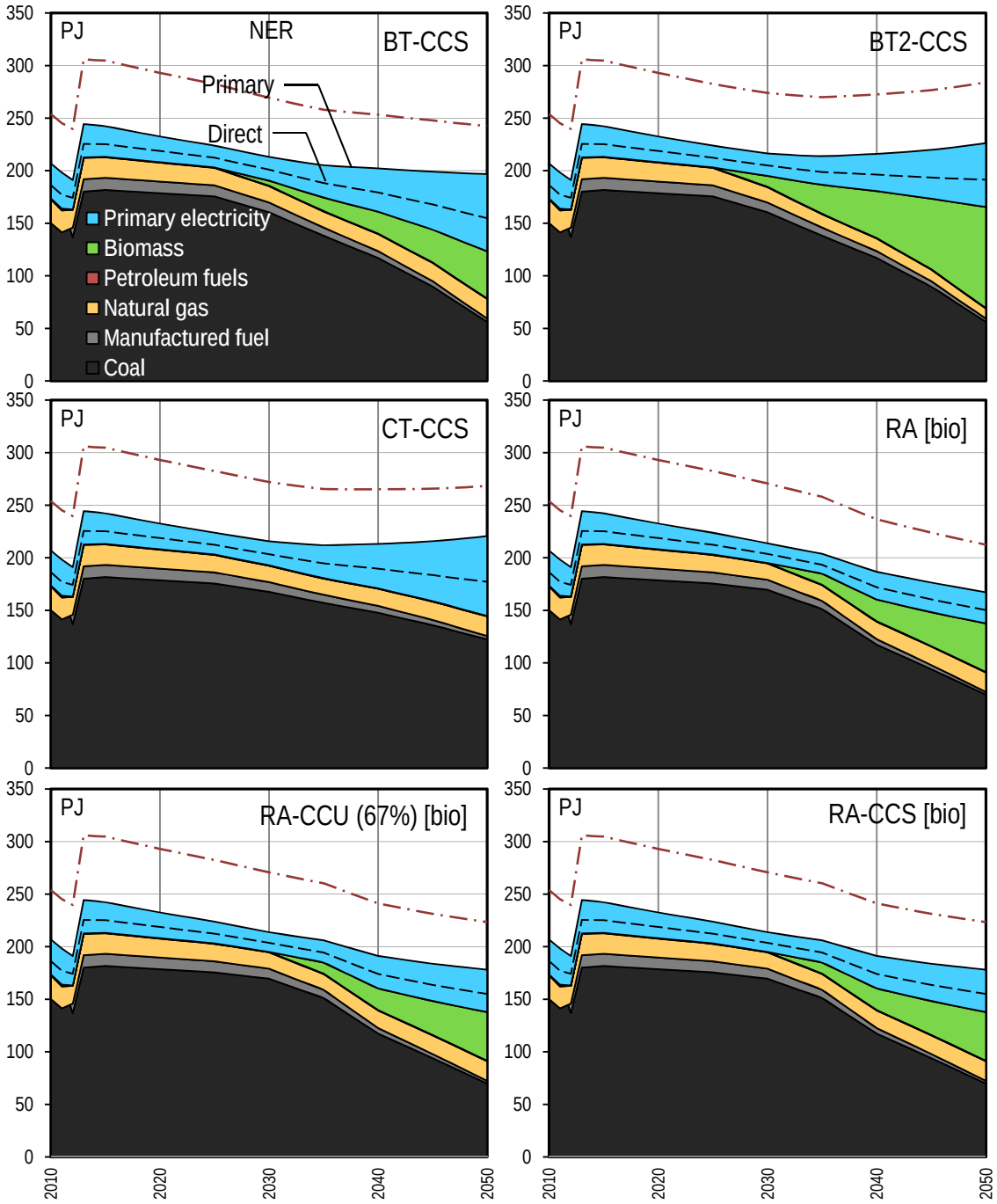

Figure A-cont'd: Energy splits of illustrative technology roadmaps of the UK iron and steel sector

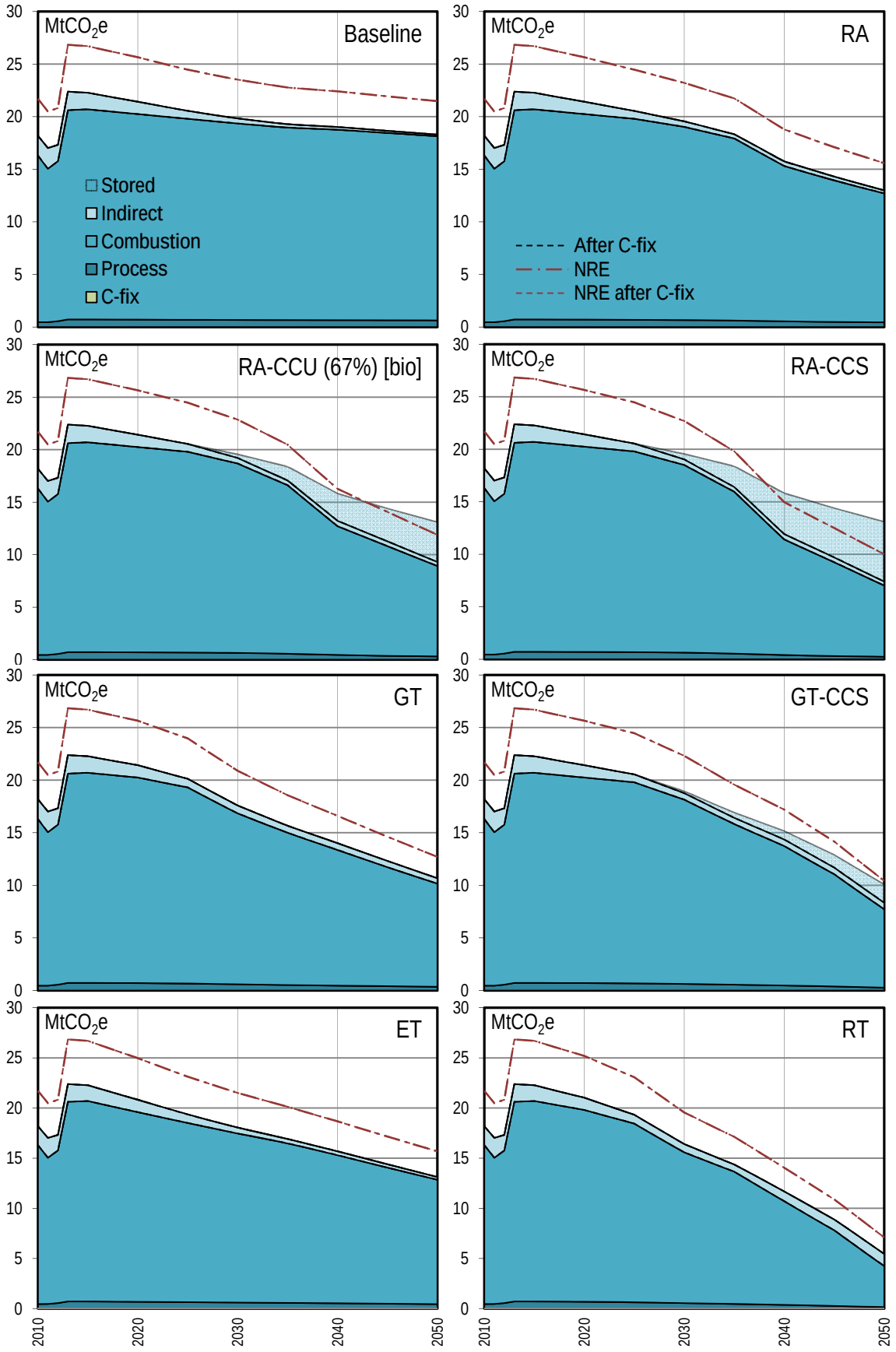

Figure A-13: GhG splits of illustrative technology roadmaps of the UK iron and steel sector

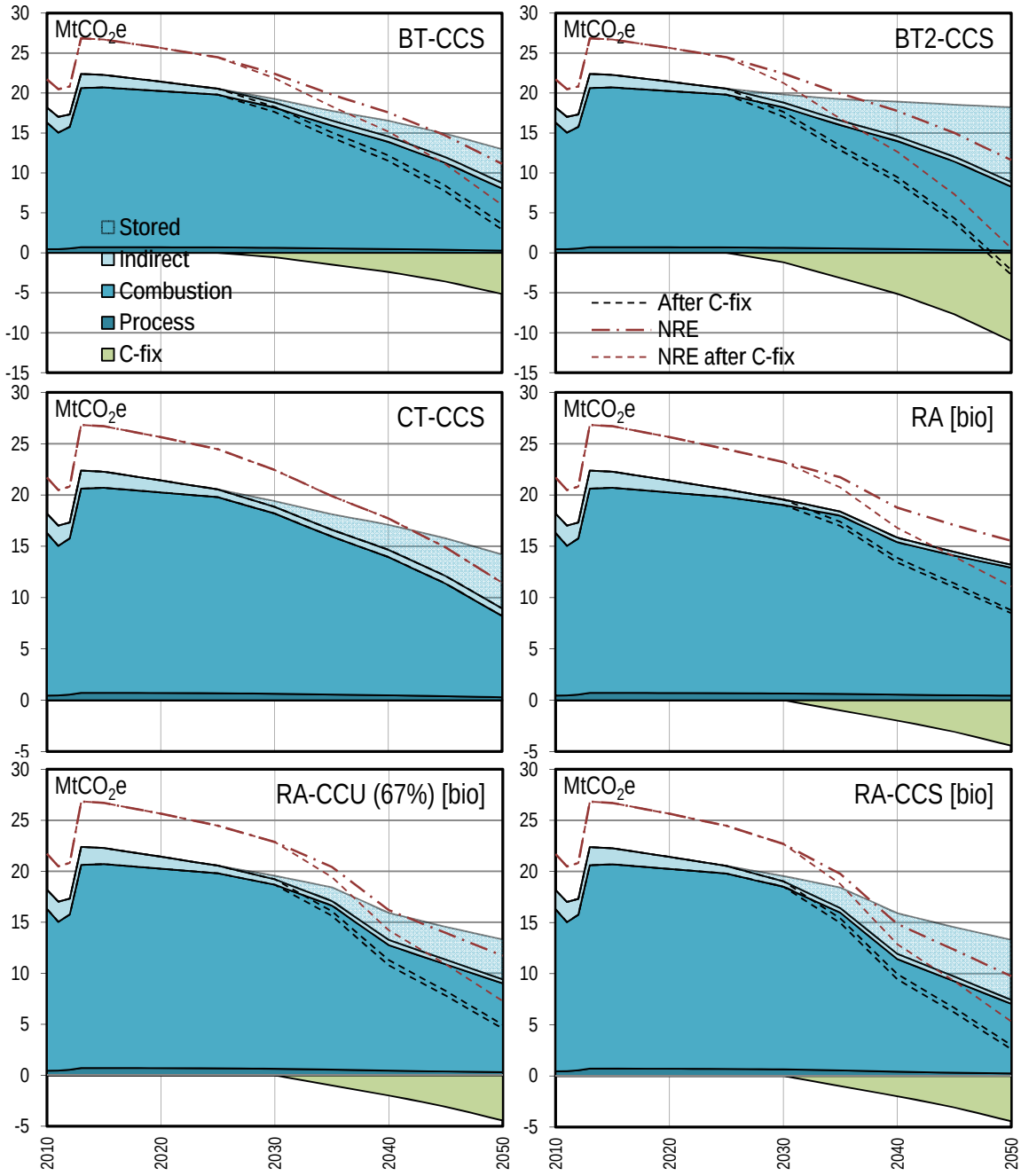

Figure A-cont'd: GhG splits of illustrative technology roadmaps of the UK iron and steel sector

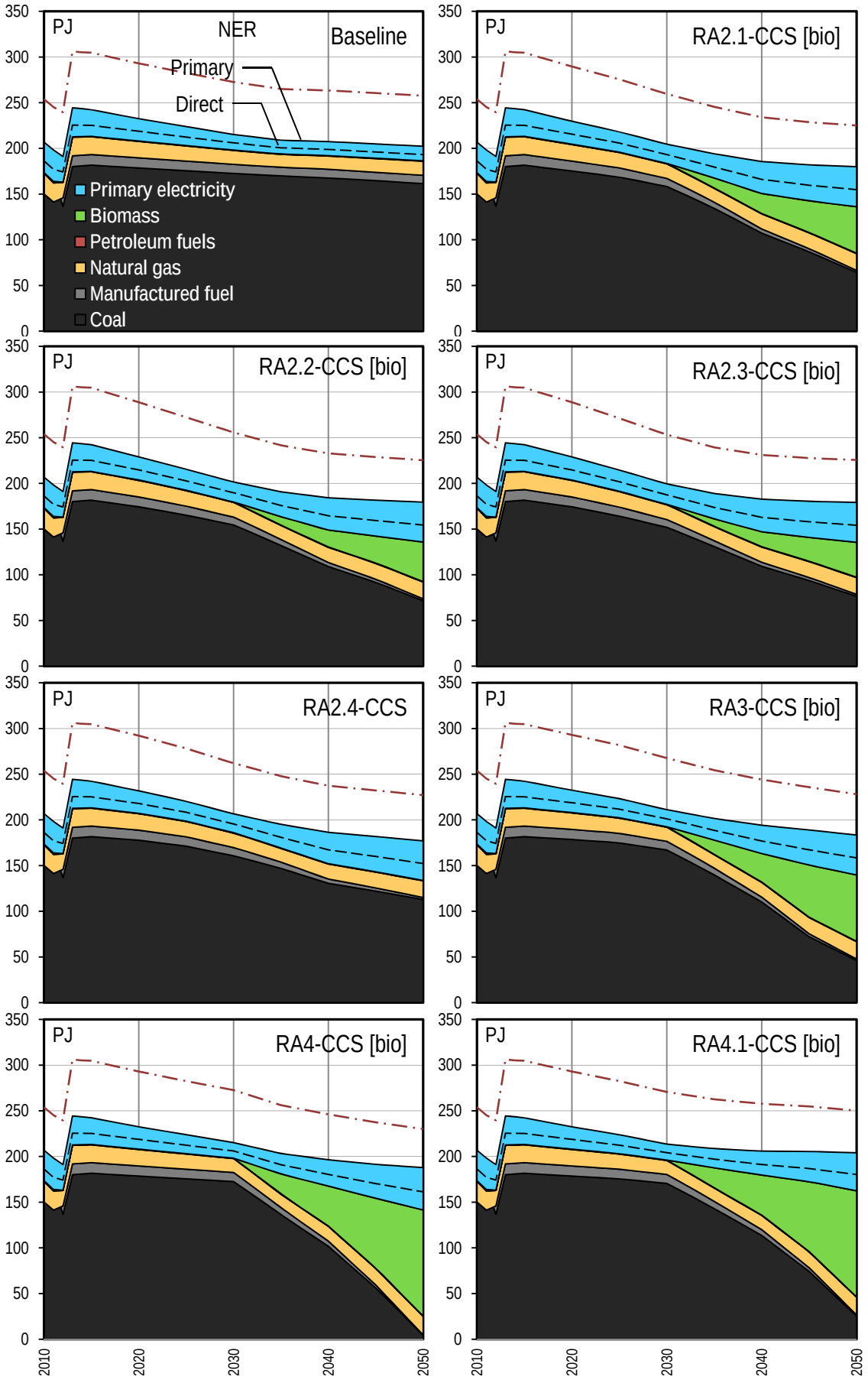

Figure A-14: Energy splits of optimised technology roadmaps of the UK iron and steel sector

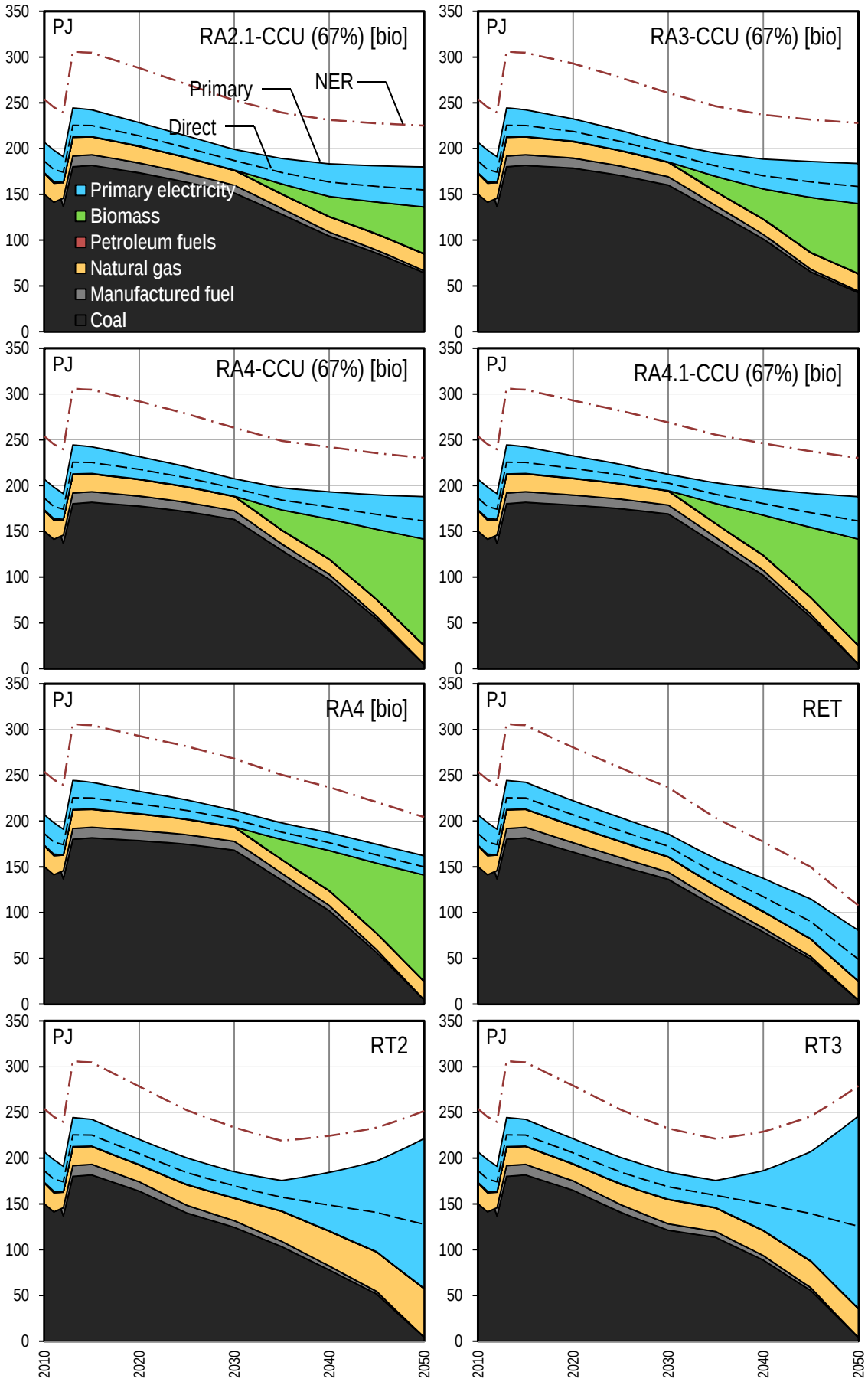

Figure A-cont'd: Energy splits of optimised technology roadmaps of the UK iron and steel sector

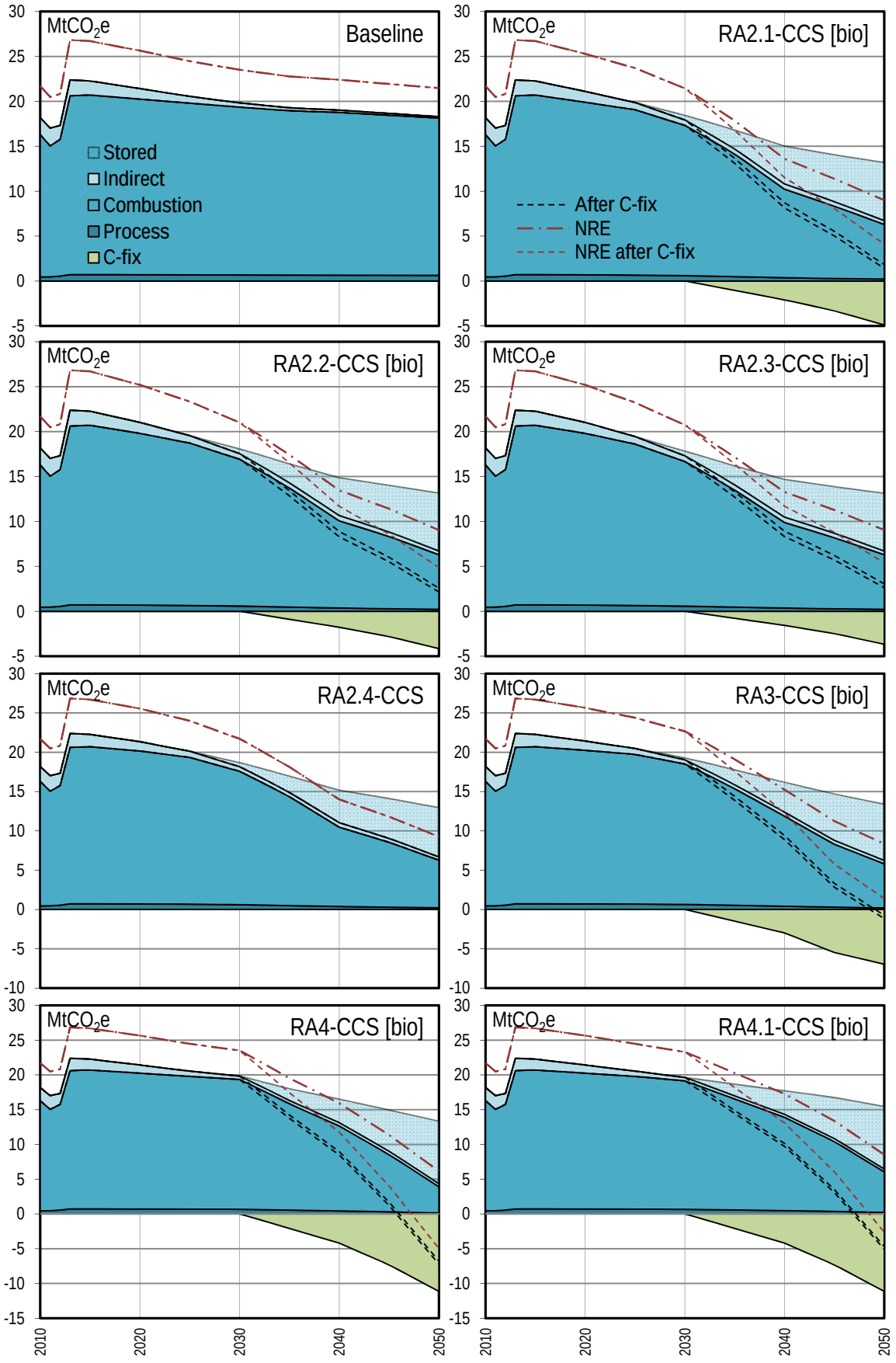

Figure A-15: GhG splits of optimised technology roadmaps of the UK iron and steel sector

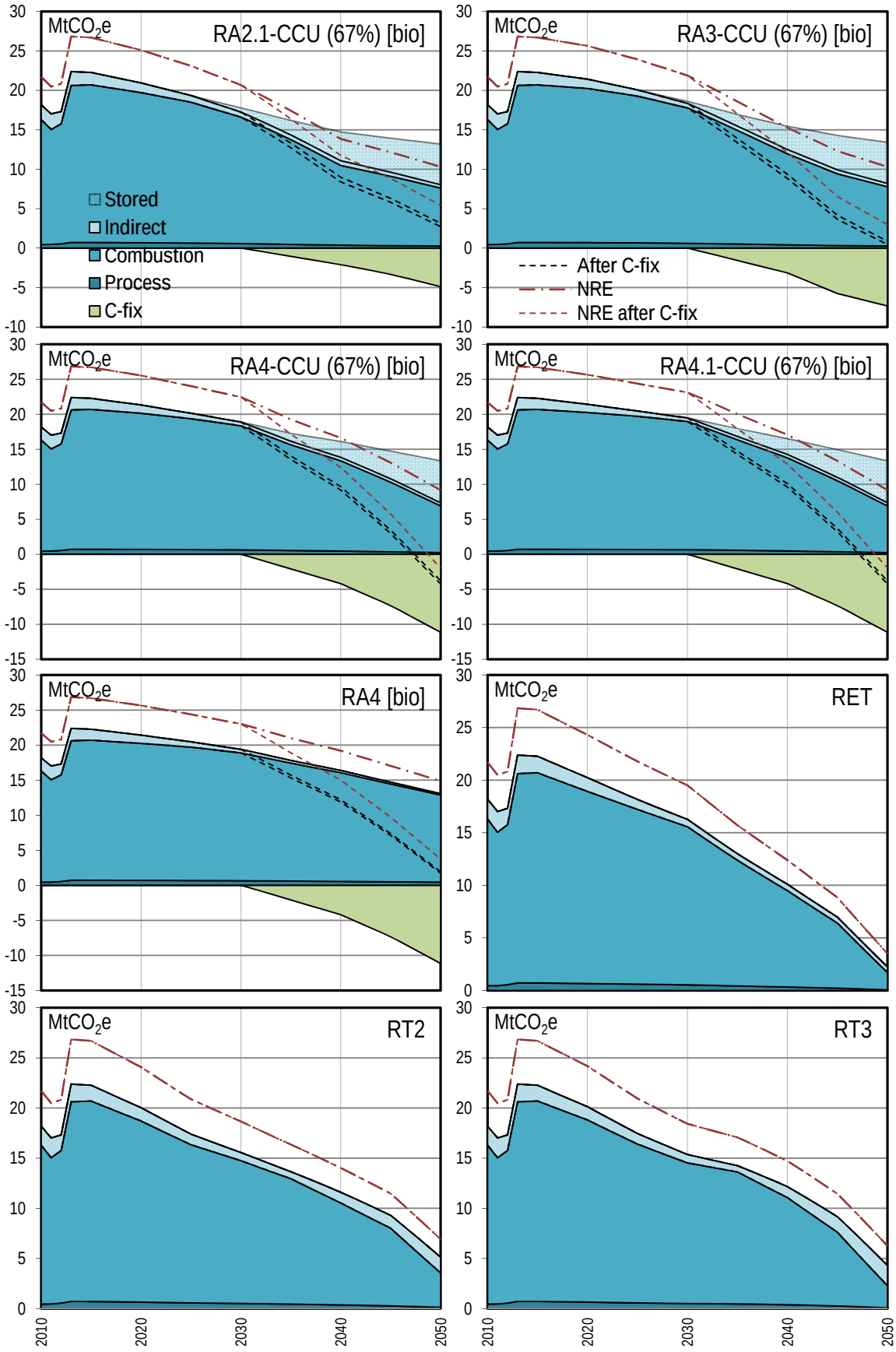

Figure A-cont'd: GhG splits of optimised technology roadmaps of the UK iron and steel sector

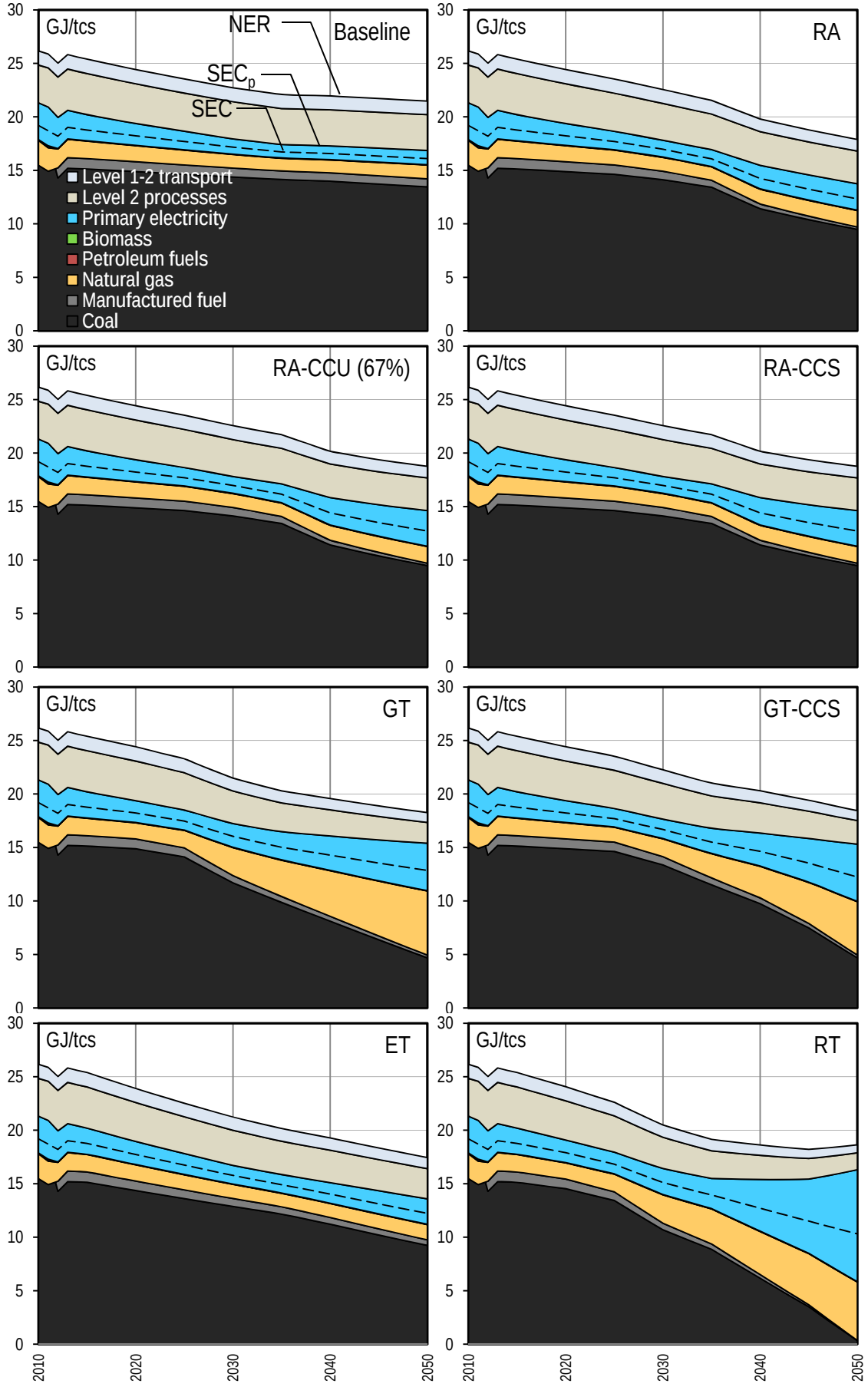

Figure A-16: Specific energy splits of illustrative technology roadmaps of the UK iron and steel sector

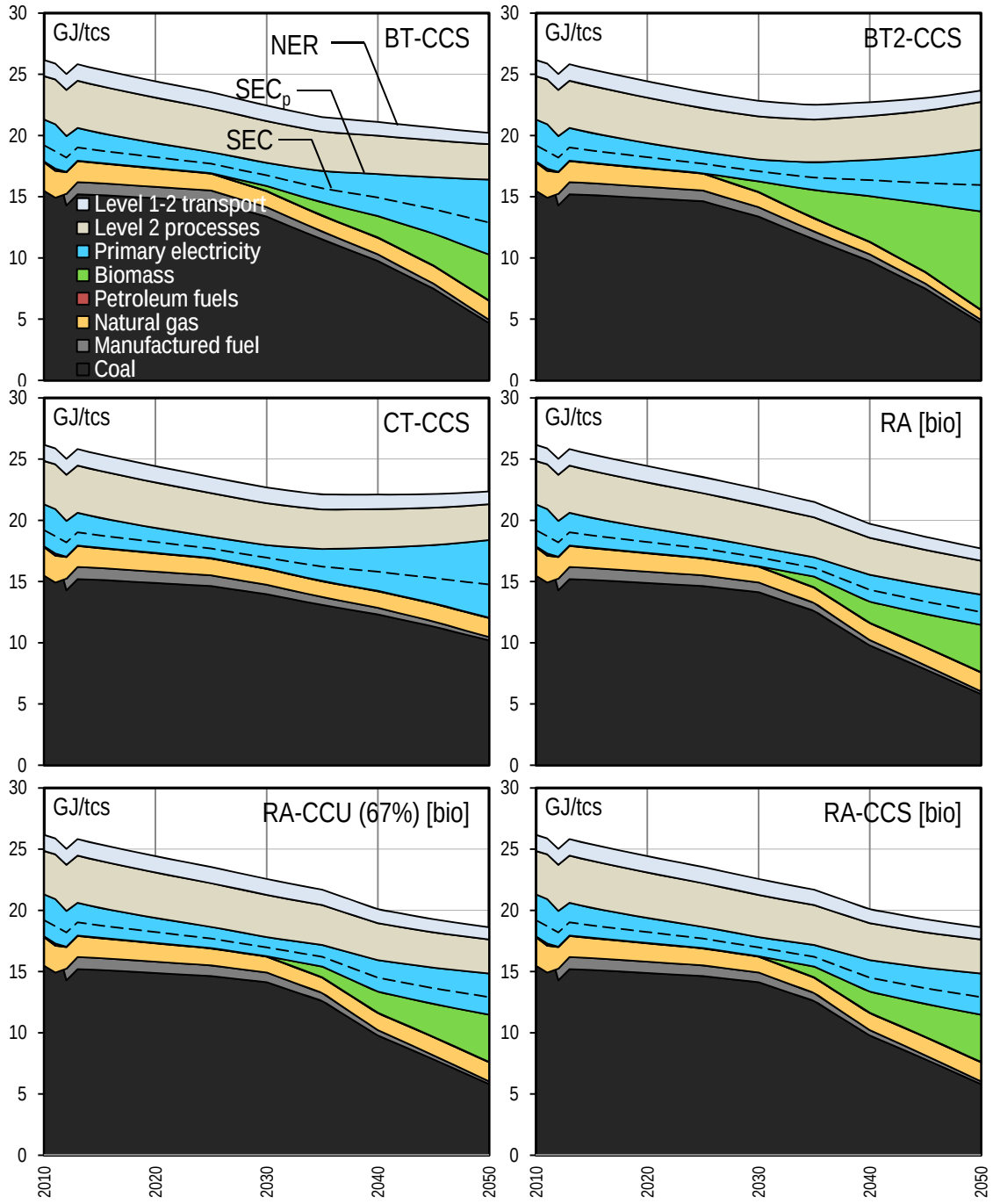

Figure A-cont'd: Specific energy splits of illustrative technology roadmaps of the UK iron and steel sector

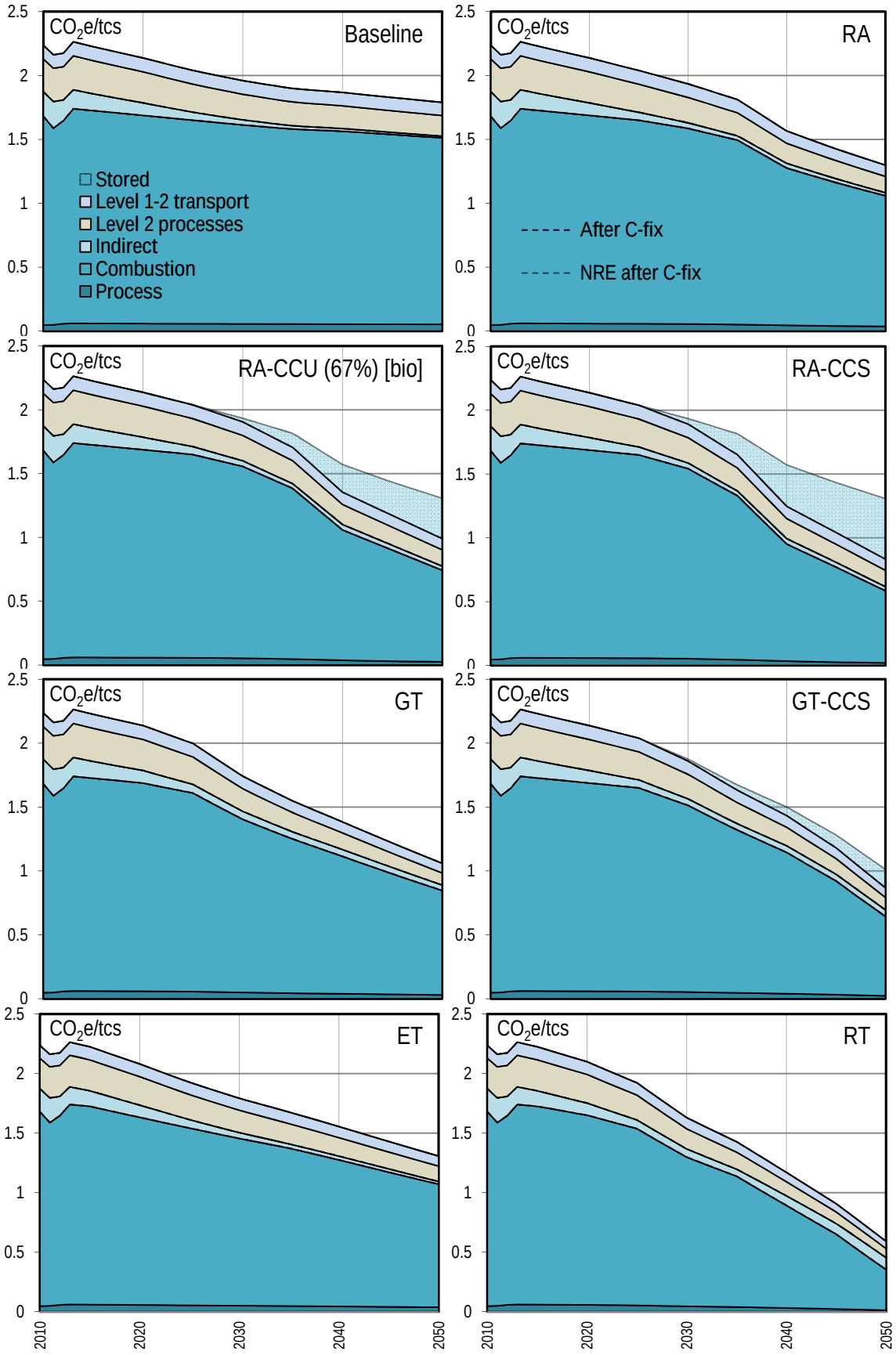

Figure A-17: Specific GhG splits of illustrative technology roadmaps of the UK iron and steel sector

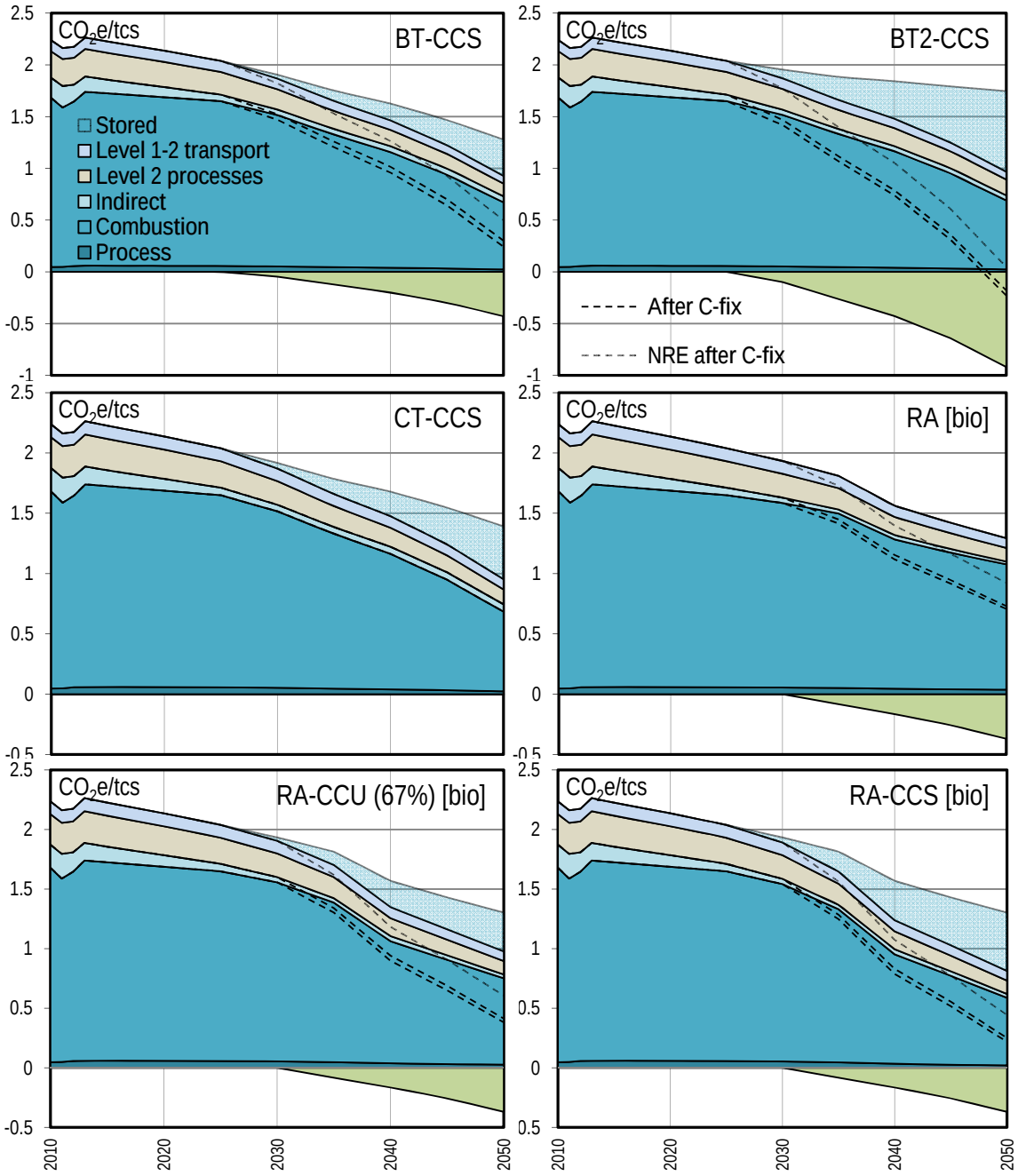

Figure A-cont'd: Specific GhG splits of illustrative technology roadmaps of the UK iron and steel sector

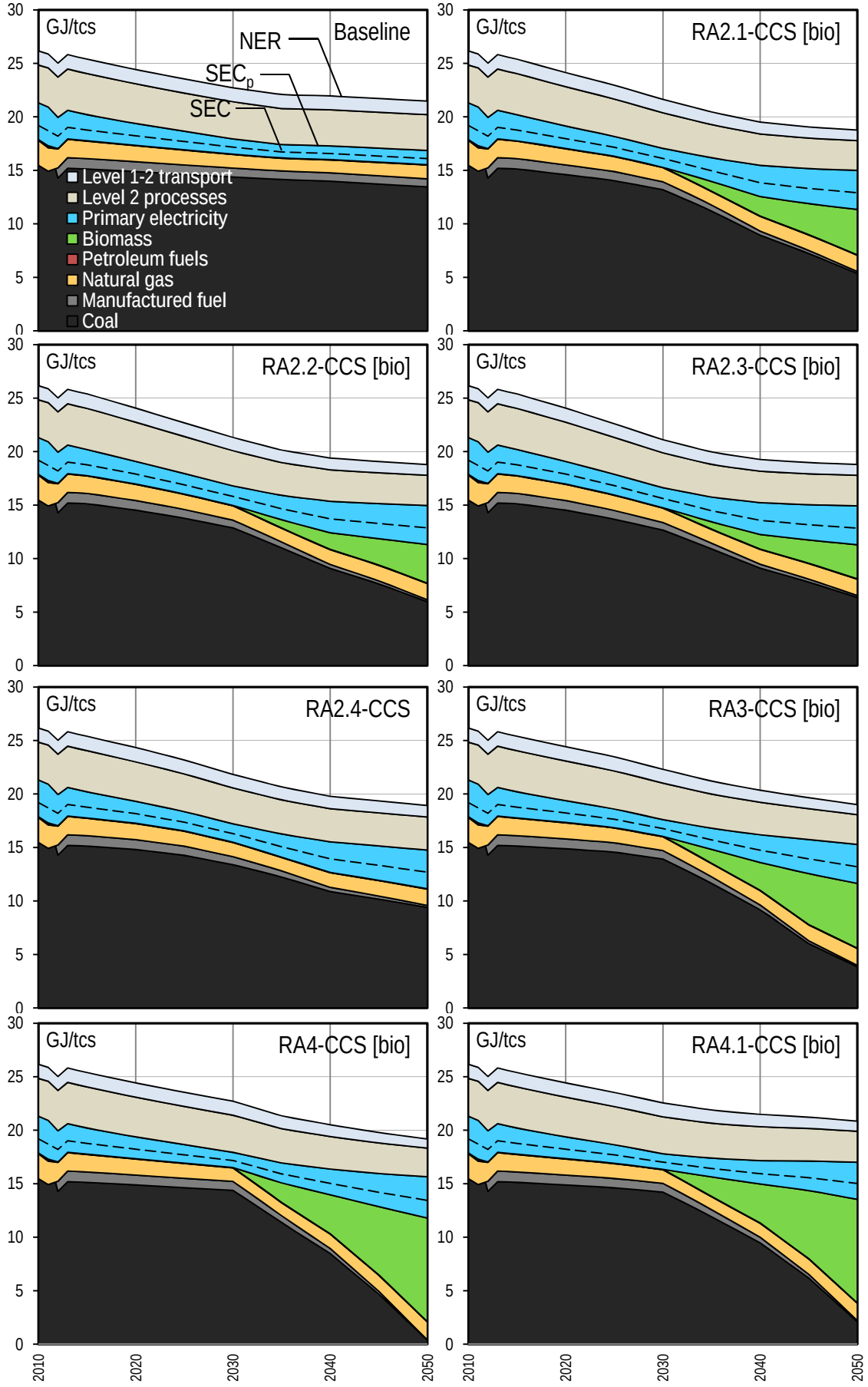

Figure A-18: Specific energy splits of optimised technology roadmaps of the UK iron and steel sector

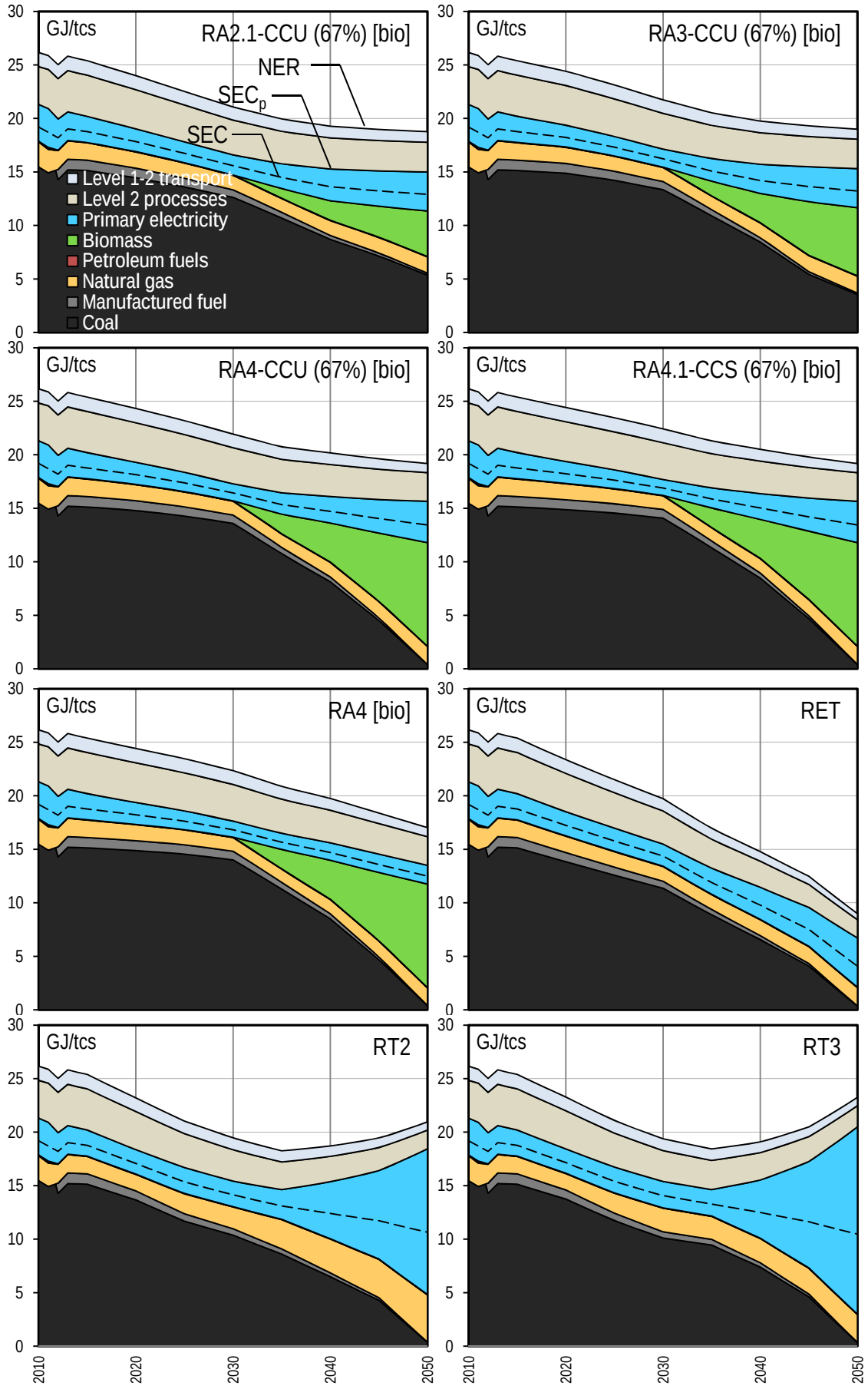

Figure A-cont'd: Specific energy splits of optimised technology roadmaps of the UK iron and steel sector

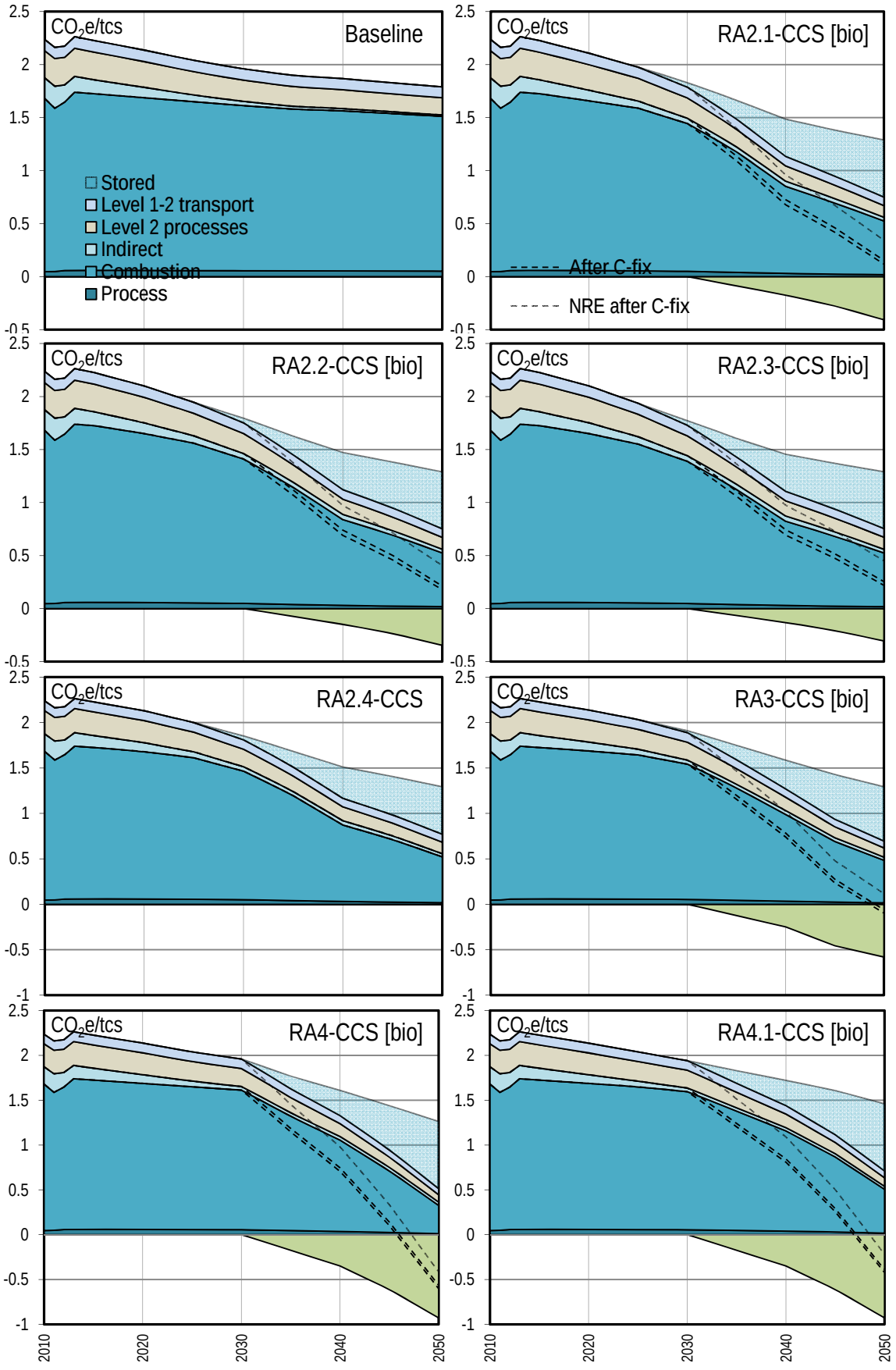

Figure A-19: Specific GhG splits of optimised technology roadmaps of the UK iron and steel sector

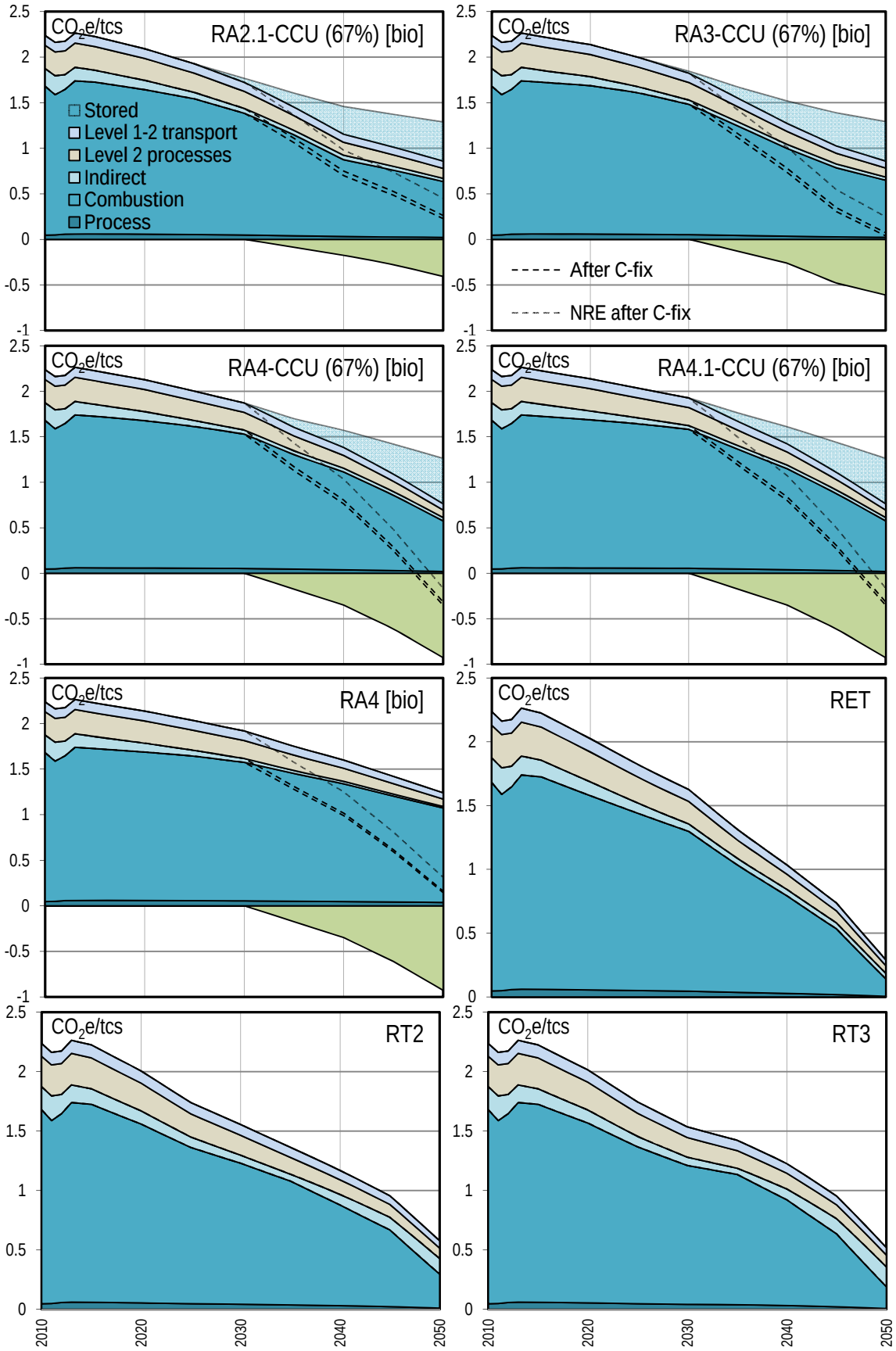

Figure A-cont'd: Specific GhG splits of optimised technology roadmaps of the UK iron and steel sector

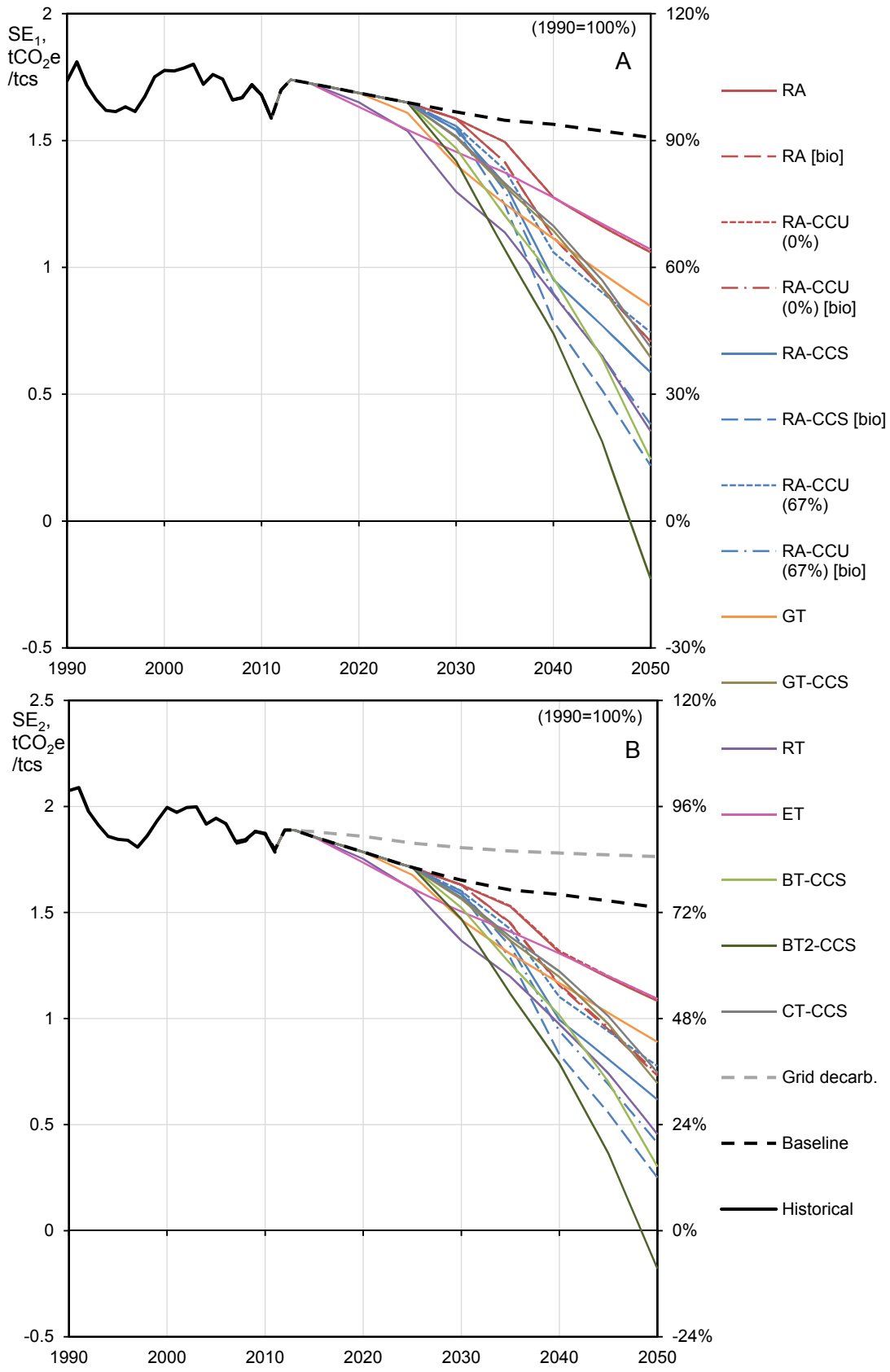

Figure A-20: Specific GhG emissions pathways of illustrative technology roadmaps for the UK iron and steel sector

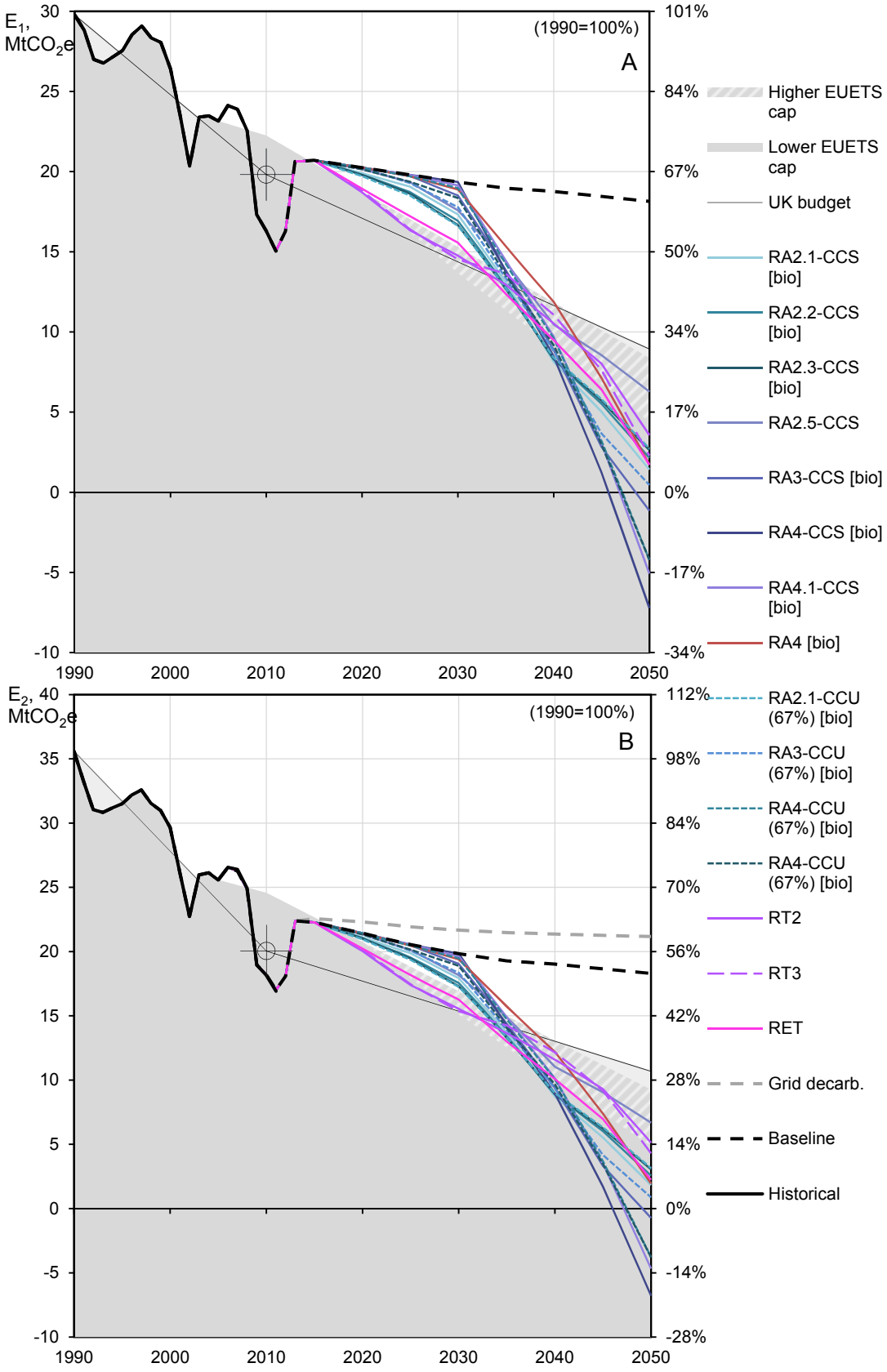

Figure A-21: Absolute GhG emissions pathways of optimised technology roadmaps for the UK iron and steel sector

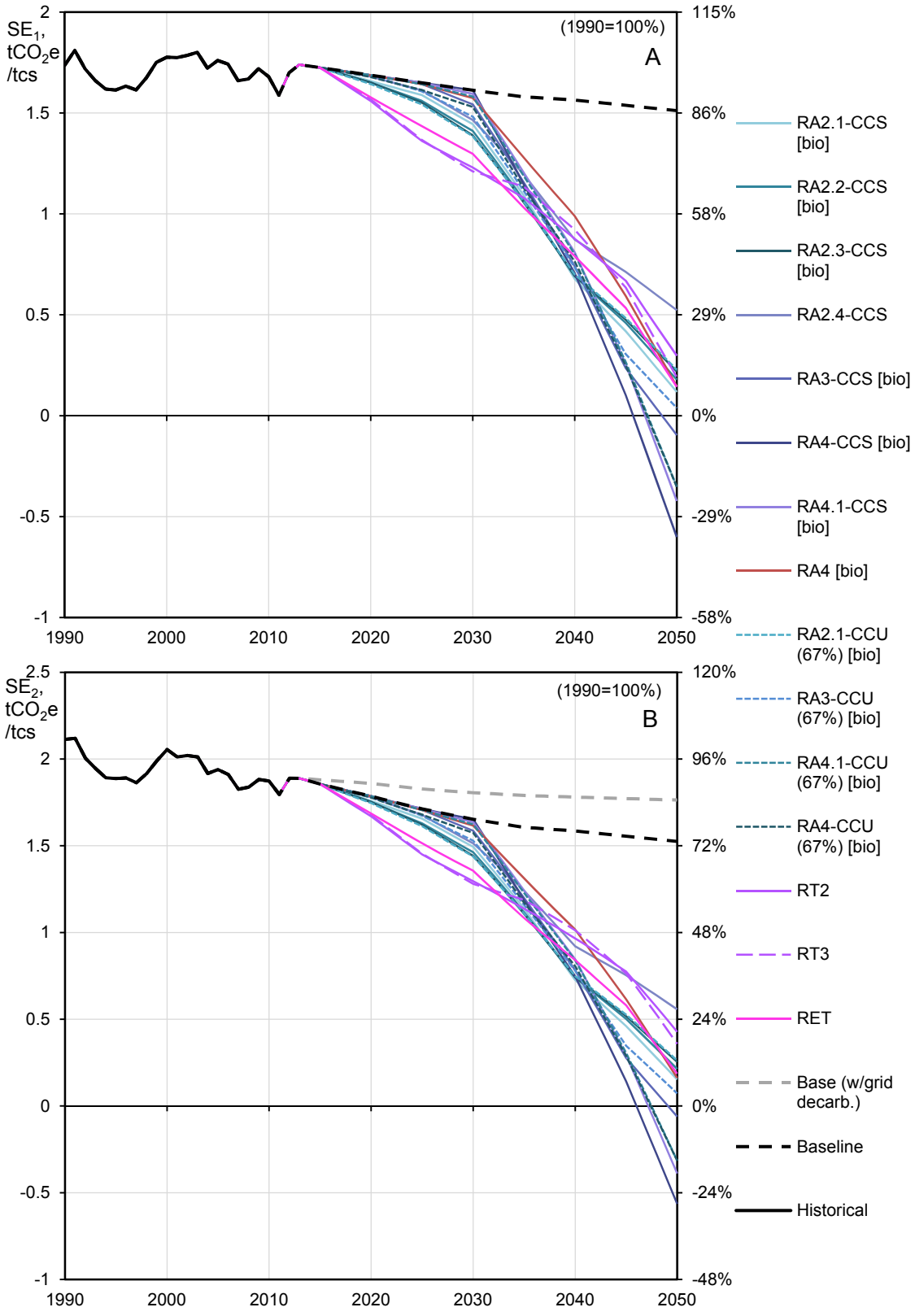

Figure A-22: Specific GhG emissions pathways of illustrative technology roadmaps for the UK iron and steel sector

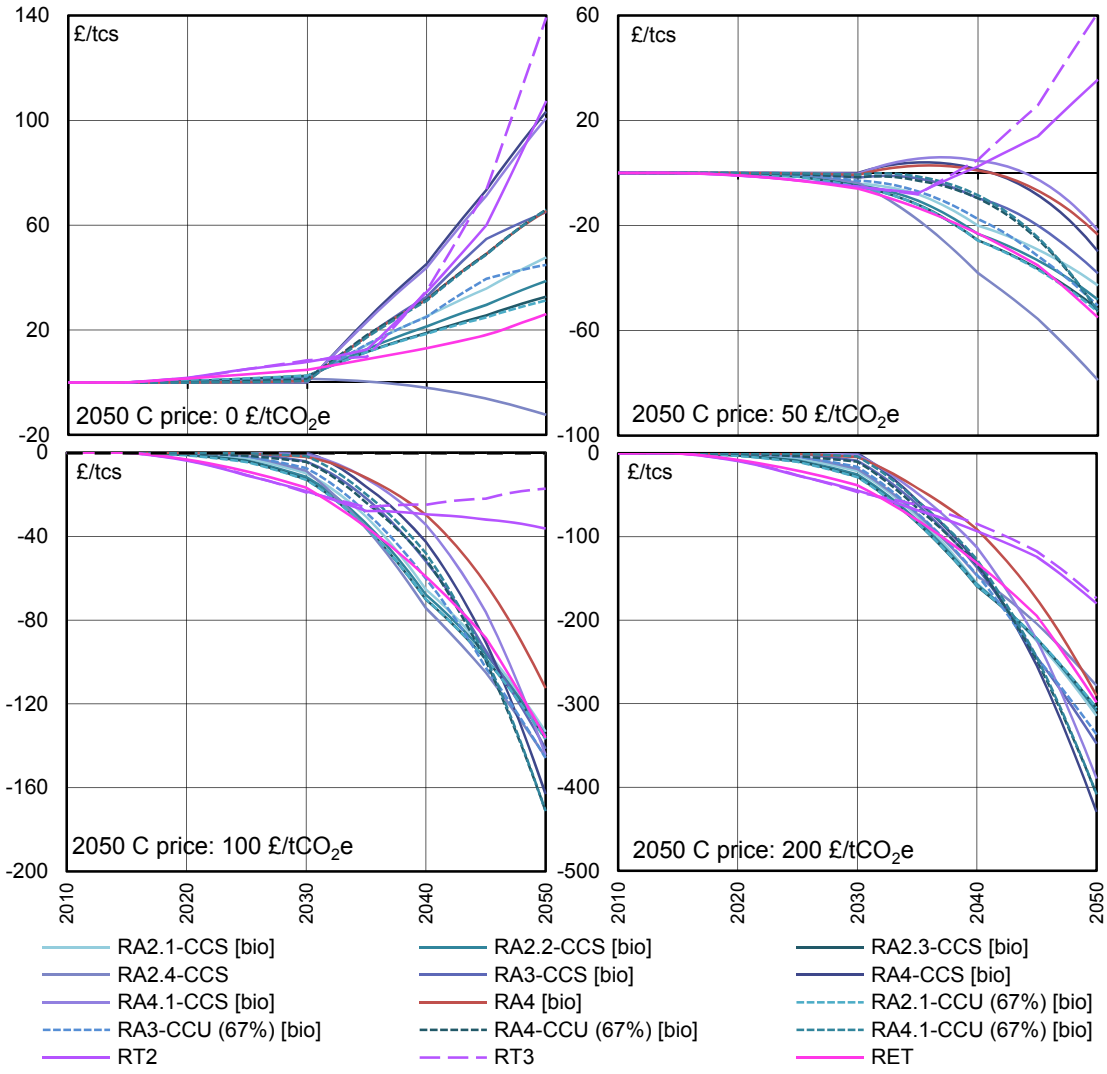

Figure A-23: Relative production cost pathways of optimised technology roadmaps of the UK iron and steel sector

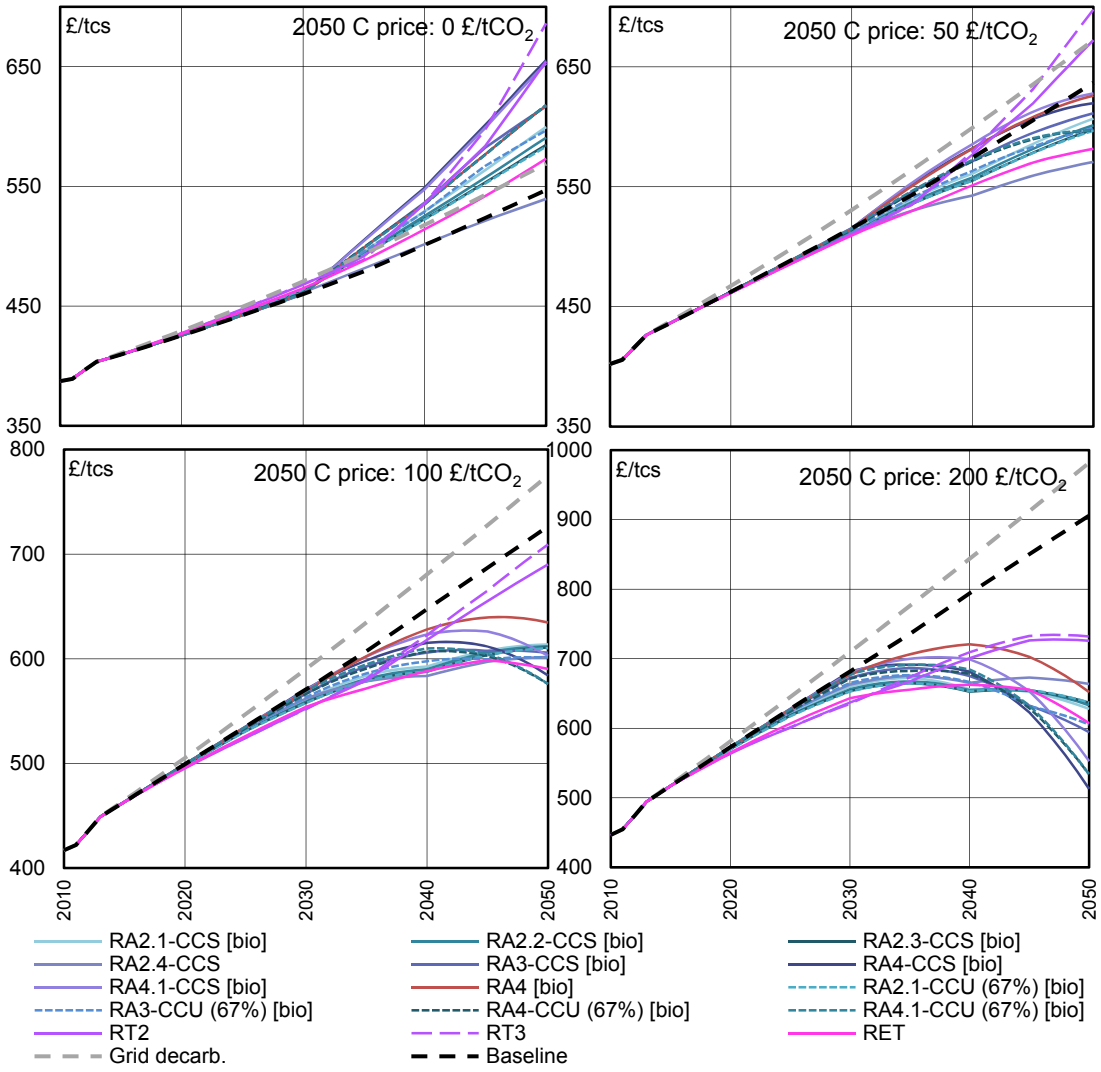

Figure A-24: Production cost pathways of illustrative technology roadmaps of the UK iron and steel sector

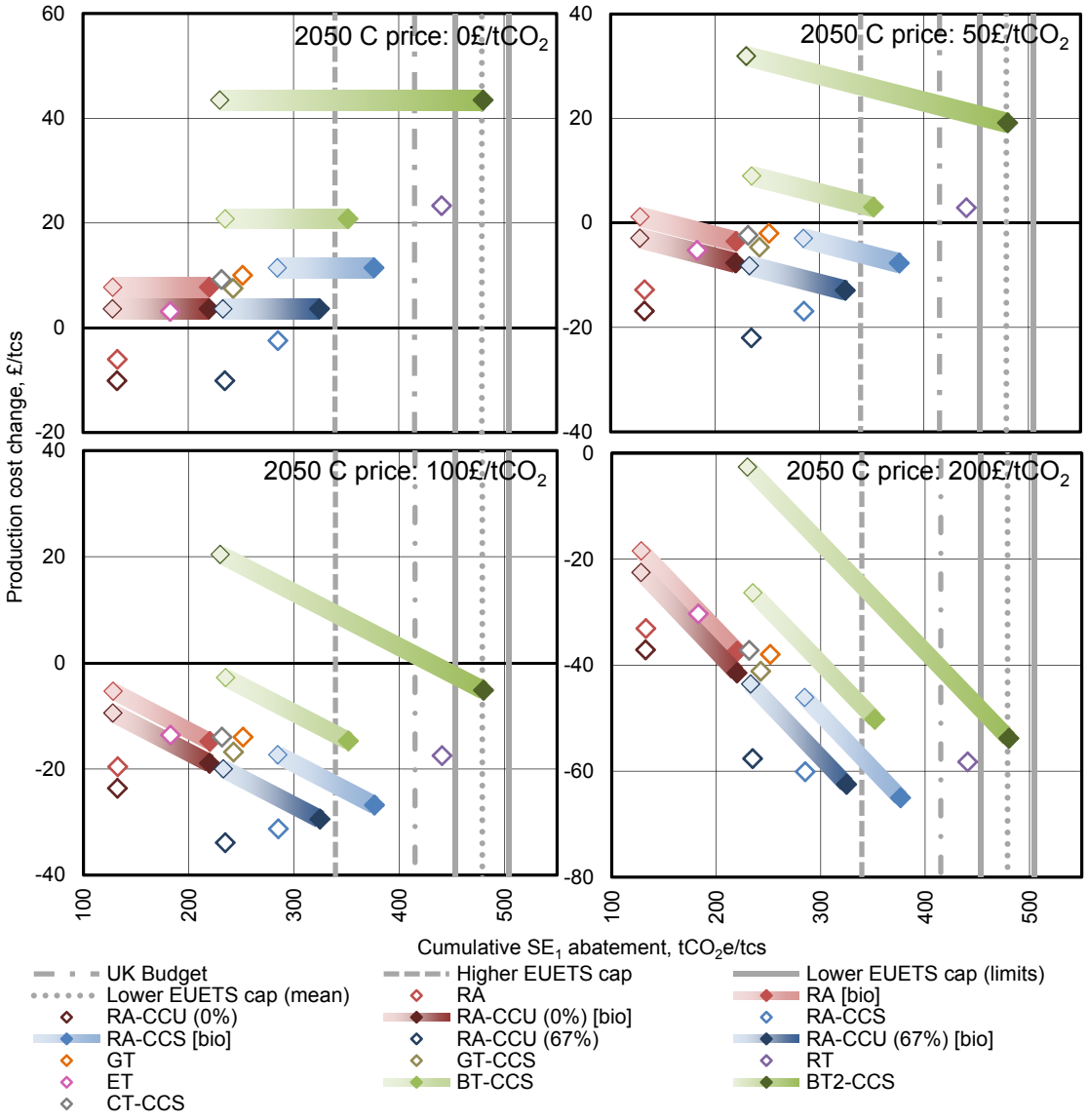

Figure A-25: Average production cost change and cumulative SE_2 abatement of illustrative technology roadmaps of the UK iron and steel sector for increasing steps of emissions trading price

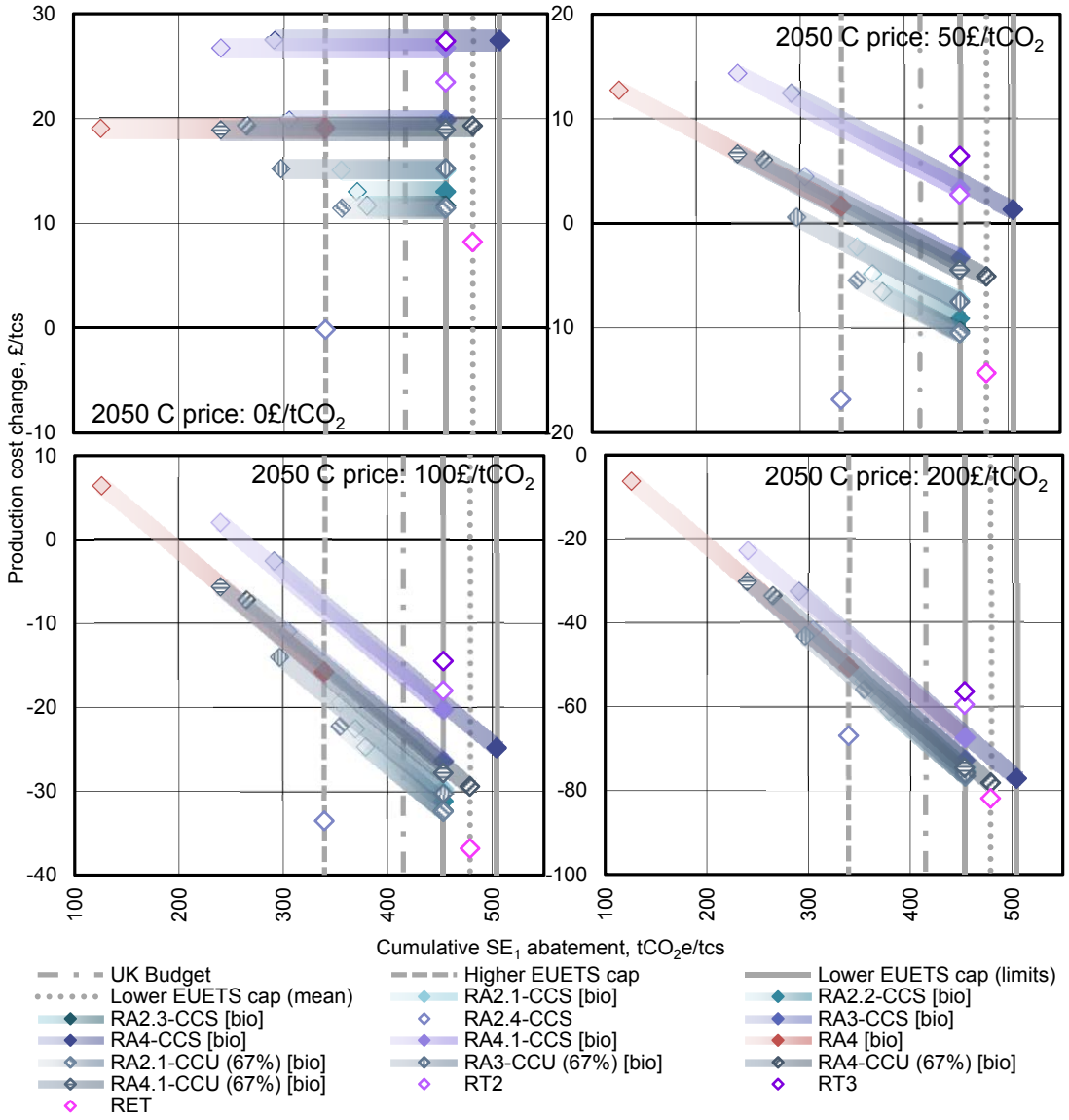

Figure A-26: Average production cost change and cumulative SE_2 abatement of optimised technology roadmaps of the UK iron and steel sector for increasing steps of emissions trading price

A5.7 Process flow diagrams

Simplified process flow diagrams of key process plant of the baseline were constructed to illustrate the general configuration of equipment and process flows. The flow ID numbers correspond to the tables in Section A5.9. The process flows are mass flows and so do not include electricity (except where it has been indicated for from the blast furnace TRT). Some minor flows are excluded.

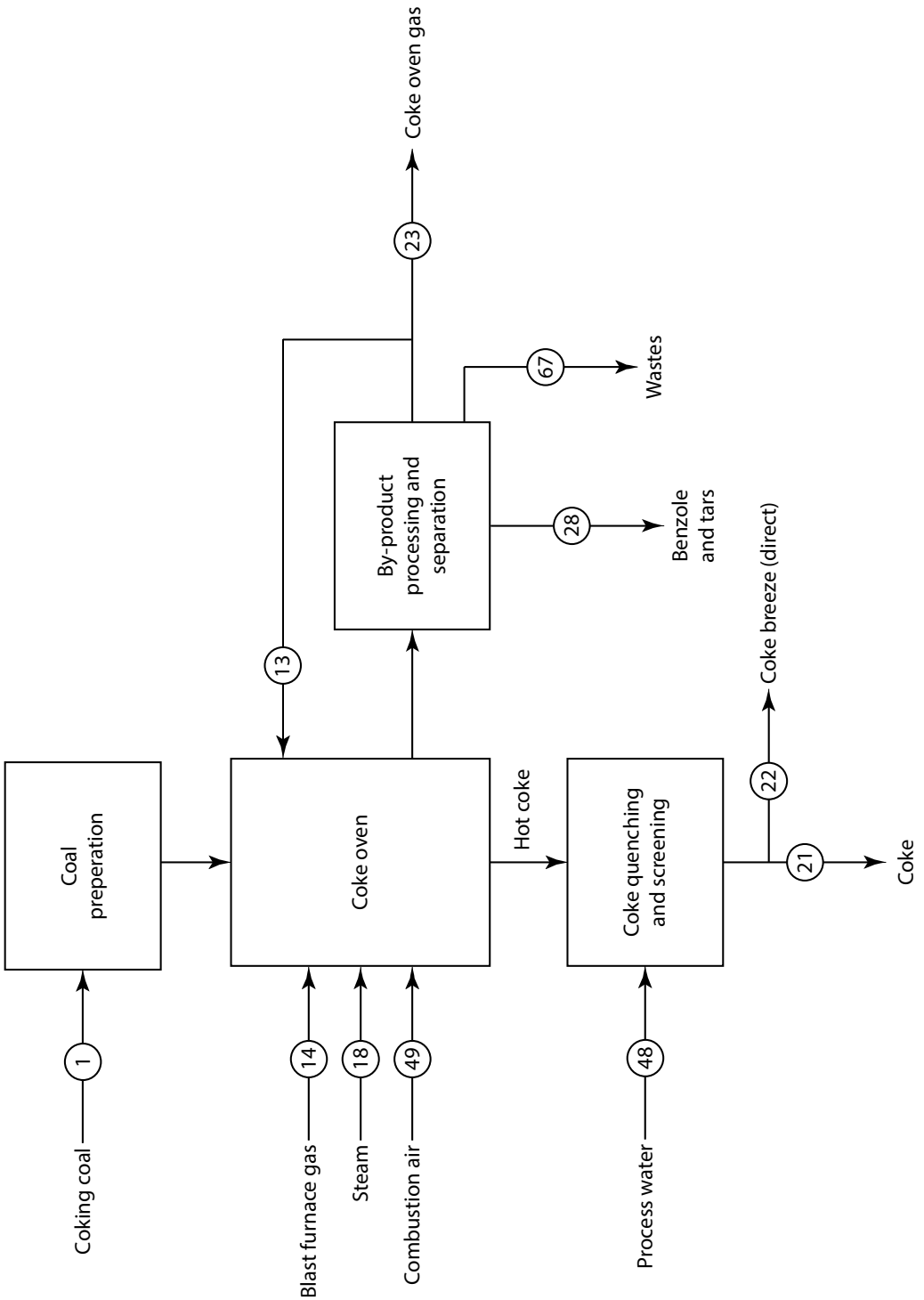

Figure A-27: Simplified process flow diagram for the metallurgical coke oven of the UK iron and steel sector (2007 average)

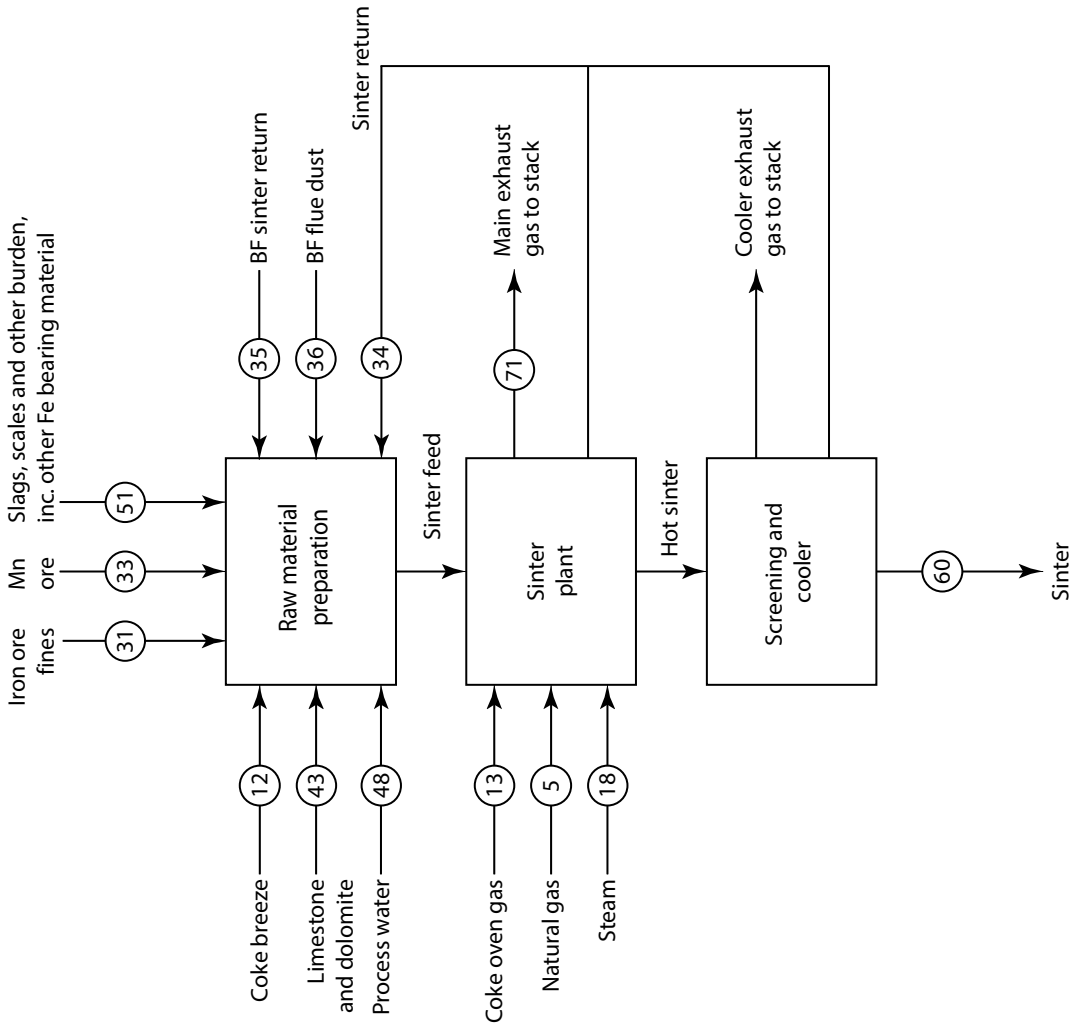

Figure A-28: Simplified process flow diagram for the UK sinter plant (2007 average)

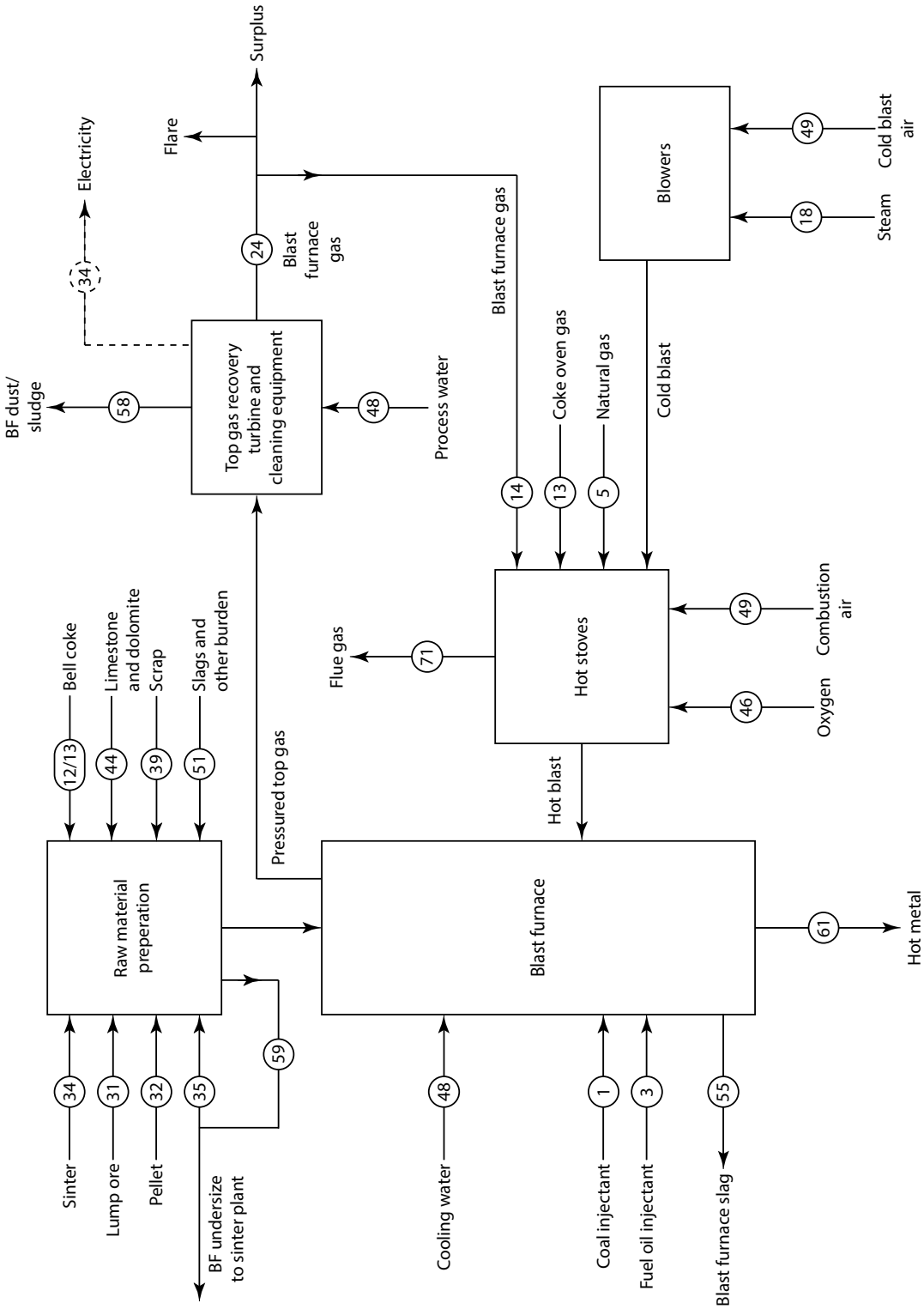

Figure A-29: Simplified process flow diagram for the UK blast furnace (2007 average)

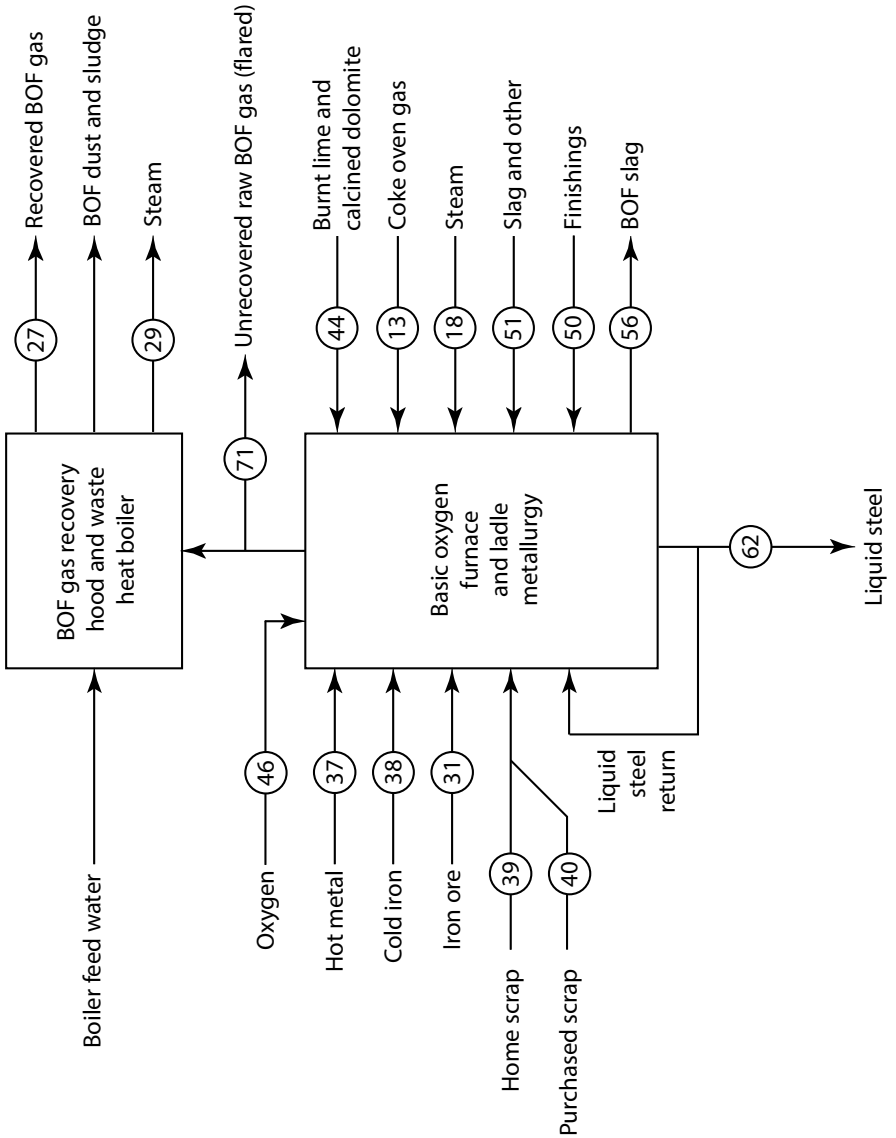

Figure A-30: Simplified process flow diagram for the UK basic oxygen furnace (2007 average)

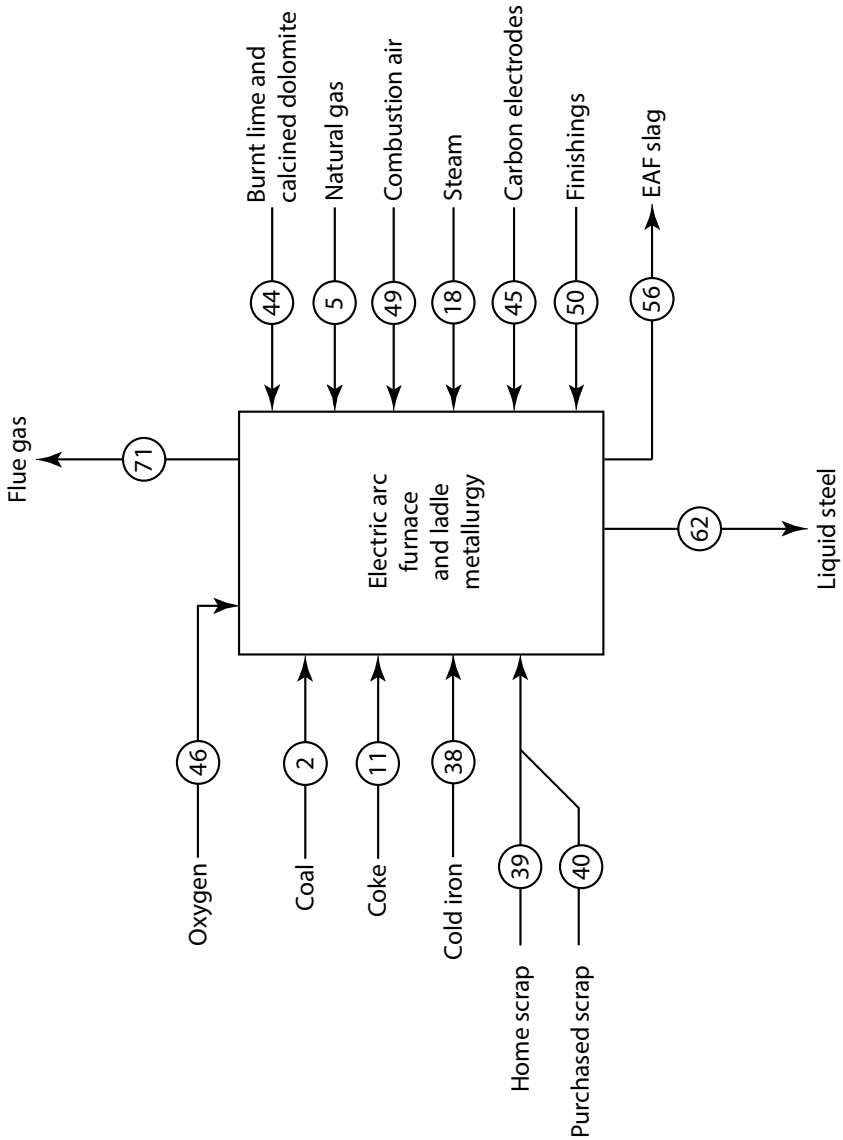

Figure A-31: Simplified process flow diagram for the UK electric arc furnace (2007 average)

A5.8 Technology site identification

Listed in Table A-18 are 4 sector representations and 16 technology site types covering 130 sites of different configuration and equipment options. Table A-19 lists a further 44 variants of the TGR-BF and HIsarna sites. Each site has an ID number* and short-hand† description. Further options for TGR-BF and HIsarna are listed in Table A-19, where x is the percentage of abatement of captured CO_2 via CCU.

Site ID	Site description
0	Sector (Base)
0p	Sector (TP)
0p2	Sector (TP2)
0b	Sector (BAT)
1	Int.wks (Base)
1p	Int.wks (TP)
1b	Int.wks (BAT)
1s	Int.wks max scrap
1bs	Int.wks max scrap (BAT)
2	EAF wks (Base)
2p2	EAF wks (TP2)
2p	EAF wks (TP)
2b	EAF wks (BAT)
3g	EAF gnf.wks
3gb	EAF gnf.wks (BAT)
4	Int.wks, MEA sep.
4b	Int.wks, MEA sep. (BAT)
4s	Int.wks, max scrap, MEA sep.
4bs	Int.wks, max scrap, MEA sep. (BAT)
5	TGR-BF wks, MDEA sep.
5b	TGR-BF wks, MDEA sep. (BAT)

* b = BAT, s = max scrap, g = Greenfield, v = VPSA, u = CCU, i = imported electricity

† Int. = integrated, wks = steelworks, sep. = separation equipment, gnf. = Greenfield, max scrap = maximum BOF scrap input (35% metallic charge), imp.elec. = imported electricity, bio. = biomass, exs = excess, syng . = syngas., V4 = version 4 of ULCOS TGR-BF configurations., x = percentage of abatement of captured CO_2 via CCU.

Site ID	Site description
5s	TGR-BF wks, max scrap, MDEA sep.
5bs	TGR-BF wks, max scrap, MDEA sep. (BAT)
5.v	TGR-BF wks, VPSA sep.
5b.v	TGR-BF wks, VPSA sep. (BAT)
5s.v	TGR-BF wks, max scrap, VPSA sep.
5bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)
6	TGR-BF wks, MDEA sep.
6b	TGR-BF wks, MDEA sep. (BAT)
6s	TGR-BF wks, max scrap, MDEA sep.
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)
6.v	TGR-BF wks, VPSA sep.
6b.v	TGR-BF wks, VPSA sep. (BAT)
6s.v	TGR-BF wks, max scrap, VPSA sep.
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)
7	HIsarna wks
7b	HIsarna wks (BAT)
7s	HIsarna wks, max scrap
7bs	HIsarna wks, max scrap (BAT)
8	HIsarna wks, MDEA sep.
8b	HIsarna wks, MDEA sep. (BAT)
8s	HIsarna wks, max scrap, MDEA sep.
8bs	HIsarna wks, max scrap, MDEA sep. (BAT)
8.v	HIsarna wks, VPSA sep.
8b.v	HIsarna wks, VPSA sep. (BAT)
8s.v	HIsarna wks, max scrap, VPSA sep.
8bs.v	HIsarna wks, max scrap, VPSA sep. (BAT)
9	MIDREX wks
9g	MIDREX gnf.wks
9b	MIDREX wks (BAT)
9.i	MIDREX wks, imp.elec.
9g.i	MIDREX gnf.wks, imp.elec.
9b.i	MIDREX wks, imp.elec. (BAT)
10	MIDREX wks MDEA sep.

Site ID	Site description
10g	MIDREX gnf.wks MDEA sep.
10b	MIDREX wks MDEA sep. (BAT)
10.v	MIDREX wks VPSA sep.
10g.v	MIDREX gnf.wks VPSA sep.
10b.v	MIDREX wks VPSA sep. (BAT)
11	ULCORED wks, NG, MDEA sep.
11g	ULCORED gnf.wks, NG, MDEA sep.
11b	ULCORED wks, NG, MDEA sep. (BAT)
11.v	ULCORED wks, NG, VPSA sep.
11g.v	ULCORED gnf.wks, NG, VPSA sep.
11b.v	ULCORED wks, NG, VPSA sep. (BAT)
11.i	ULCORED wks, imp.elec., NG, MDEA sep.
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)
12	ULCORED wks, coal, MDEA sep.
12g	ULCORED gnf.wks, coal, MDEA sep.
12b	ULCORED wks, coal, MDEA sep. (BAT)
12.v	ULCORED wks, coal, VPSA sep.
12g.v	ULCORED gnf.wks, coal, VPSA sep.
12b.v	ULCORED wks, coal, VPSA sep. (BAT)
12.i	ULCORED wks, imp.elec., coal, MDEA sep.
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)
13	ULCORED wks, exs coal syng., MDEA sep.
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)
13.v	ULCORED wks, exs coal syng., VPSA sep.

Site ID	Site description
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)
14	ULCORED wks, bio., MDEA sep.
14g	ULCORED gnf.wks, bio., MDEA sep.
14b	ULCORED wks, bio., MDEA sep. (BAT)
14.v	ULCORED wks, bio., VPSA sep.
14g.v	ULCORED gnf.wks, bio., VPSA sep.
14b.v	ULCORED wks, bio., VPSA sep. (BAT)
14.i	ULCORED wks, imp.elec., bio., MDEA sep.
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)
15	ULCORED wks, exs bio.syng., MDEA sep.
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)
15.v	ULCORED wks, exs bio.syng., VPSA sep.
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)
15	ULCORED wks, exs bio.syng., MDEA sep.

Site ID	Site description
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)
15.v	ULCORED wks, exs bio.syng., VPSA sep.
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)
16	ULCOWIN wks, imp.elec.
16g	ULCOWIN gnf.wks, imp.elec.
16b	ULCOWIN wks, imp.elec. (BAT)

Table A-18: Baseline and future sectors and sites of the UK iron and steel sector with site ID and short-hand description

Site ID	Site description
5.2	TGR-BF [V4] wks, MDEA sep.
5.2b	TGR-BF [V4] wks, MDEA sep. (BAT)
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep.
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)
5.2.v	TGR-BF [V4] wks, VPSA sep.
5.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)
6.2	TGR-BF [V4] wks, MDEA sep.
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)
6.2.v	TGR-BF [V4] wks, VPSA sep.
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.

Site ID	Site description
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)
7.2	HIsarna [bio] wks
7.2b	HIsarna [bio] wks (BAT)
7.2s	HIsarna [bio] wks, max scrap
7.2bs	HIsarna [bio] wks, max scrap (BAT)
8.2	HIsarna [bio] wks, MDEA sep.
8.2b	HIsarna [bio] wks, MDEA sep. (BAT)
8.2s	HIsarna [bio] wks, max scrap, MDEA sep.
8.2bs	HIsarna [bio] wks, max scrap, MDEA sep. (BAT)
8.2.v	HIsarna [bio] wks, VPSA sep.
8.2b.v	HIsarna [bio] wks, VPSA sep. (BAT)
8.2s.v	HIsarna [bio] wks, max scrap, VPSA sep.
8.2bs.v	HIsarna [bio] wks, max scrap, VPSA sep. (BAT)
5.2.u	TGR-BF [V4] wks, MDEA sep. [x%CCU]
5.2b.u	TGR-BF [V4] wks, MDEA sep. [x%CCU] (BAT)
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [x%CCU]
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [x%CCU] (BAT)
5.2.vu	TGR-BF [V4] wks, VPSA sep. [x%CCU]
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [x%CCU] (BAT)
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [x%CCU]
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [x%CCU] (BAT)
8.2.u	HIsarna [bio] wks, MDEA sep. [x%CCU]
8.2b.u	HIsarna [bio] wks, MDEA sep. [x%CCU] (BAT)
8.2s.u	HIsarna [bio] wks, max scrap, MDEA sep. [x%CCU]
8.2bs.u	HIsarna [bio] wks, max scrap, MDEA sep. [x%CCU] (BAT)
8.2.vu	HIsarna [bio] wks, VPSA sep. [x%CCU]
8.2b.vu	HIsarna [bio] wks, VPSA sep. [x%CCU] (BAT)
8.2s.vu	HIsarna [bio] wks, max scrap, VPSA sep. [x%CCU]
8.2bs.vu	HIsarna [bio] wks, max scrap, VPSA sep. [x%CCU] (BAT)

Table A-19: Baseline and future sectors and sites of the UK iron and steel sector with site ID and short-hand description – other variants of TGR-BF and HIsarna sites

A5.9 Energy, emissions and economics summaries

The tables present the results of energy, emissions and economic assessment applied to the modelled sectors and sites of the UK iron and steel sector. In tables with abatements and abatement costs, cells shaded grey represent variants that do not use the base integrated steelworks (1) as their baseline; aggregated sector representations and base EAF sites use the base sector (0) and the base EAF site (2) as their baselines respectively.

ID	Description	Output (2007)	SEC	SEC_p	PER - Scope I	GER - Scope I	NER - Scope I	PER - Scope II	GER - Scope II	NER - Scope II
		ktcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs
0	Sector (Base)	14,390	18.23	20.14	15.52	39.59	24.67	9.40	25.11	24.67
0p	Sector (TP)	14,390	16.43	17.82	13.82	36.19	22.15	7.63	22.51	22.15
0p2	Sector (TP2)	14,390	16.37	17.67	13.64	36.01	21.96	7.45	22.33	21.96
0b	Sector (BAT)	14,390	15.74	16.41	12.08	33.72	20.66	6.16	21.00	20.66
1	Int.wks (Base)	11,362	21.67	23.00	16.56	46.96	28.07	8.81	28.63	28.07
1p	Int.wks (TP)	11,362	19.58	20.39	14.73	42.98	25.19	6.89	25.65	25.19
1b	Int.wks (BAT)	11,362	18.93	18.95	12.96	40.26	23.73	5.46	24.16	23.73
1s	Int.wks max scrap	11,362	17.88	19.11	14.59	38.17	23.50	8.54	23.91	23.50
1bs	Int.wks max scrap (BAT)	11,362	15.52	15.57	11.46	32.64	19.78	5.59	20.10	19.78
2	EAF wks (Base)	3,028	5.29	9.42	11.64	11.94	11.94	11.64	11.94	11.94
2p2	EAF wks (TP2)	3,028	4.29	7.48	9.55	9.85	9.85	9.55	9.85	9.85
2p	EAF wks (TP)	3,028	4.57	8.22	10.41	10.71	10.71	10.41	10.71	10.71
2b	EAF wks (BAT)	3,028	3.78	6.88	8.79	9.16	9.16	8.79	9.16	9.16
3g	EAF gnf.wks	11,362	4.58	8.40	10.71	11.06	11.06	10.71	11.06	11.06
3gb	EAF gnf.wks (BAT)	11,362	3.78	6.66	8.73	9.10	9.10	8.73	9.10	9.10
4	Int.wks, MEA sep.	11,362	27.96	30.30	23.86	54.26	35.37	16.08	35.89	35.37
4b	Int.wks, MEA sep. (BAT)	11,362	22.78	24.48	18.49	45.79	29.26	10.99	29.69	29.26
4s	Int.wks, max scrap, MEA sep.	11,362	22.82	24.85	20.35	43.91	29.24	14.29	29.65	29.24
4bs	Int.wks, max scrap, MEA sep. (BAT)	11,362	18.60	20.07	15.94	37.10	24.24	10.08	24.57	24.24
5	TGR-BF wks, MDEA sep. w/o storage	11,362	22.08	24.19	24.20	48.35	28.78	13.12	29.18	28.78
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	11,362	19.04	20.83	21.42	45.28	25.30	9.93	25.70	25.30
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	11,362	18.16	19.95	20.43	39.17	23.97	11.82	24.28	23.97
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	11,362	15.66	17.17	18.12	36.63	21.09	9.17	21.40	21.09
5.v	TGR-BF wks, VPSA sep. w/o storage	11,362	19.99	22.52	22.53	46.68	27.11	11.44	27.51	27.11
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	11,362	17.21	19.41	20.00	43.86	23.88	8.51	24.28	23.88
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	11,362	16.53	18.65	19.13	37.86	22.66	10.51	22.97	22.66
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	11,362	14.04	15.86	16.82	35.32	19.79	7.87	20.10	19.79
6	TGR-BF wks, MDEA sep.	11,362	22.08	24.19	24.20	48.35	28.78	13.12	29.18	28.78
6b	TGR-BF wks, MDEA sep. (BAT)	11,362	19.04	20.83	21.42	45.28	25.30	9.93	25.70	25.30
6s	TGR-BF wks, max scrap, MDEA sep.	11,362	18.16	19.95	20.43	39.17	23.97	11.82	24.28	23.97
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	11,362	15.66	17.17	18.12	36.63	21.09	9.17	21.40	21.09
6.v	TGR-BF wks, VPSA sep.	11,362	19.99	22.52	22.53	46.68	27.11	11.44	27.51	27.11
6b.v	TGR-BF wks, VPSA sep. (BAT)	11,362	17.21	19.41	20.00	43.86	23.88	8.51	24.28	23.88
6s.v	TGR-BF wks, max scrap, VPSA sep.	11,362	16.53	18.65	19.13	37.86	22.66	10.51	22.97	22.66
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	11,362	14.04	15.86	16.82	35.32	19.79	7.87	20.10	19.79
7	Hlsarna wks	11,362	17.15	17.30	8.48	23.34	22.99	8.54	22.99	22.99
7b	Hlsarna wks (BAT)	11,362	16.02	15.73	7.31	22.17	21.41	6.96	21.41	21.41
7s	Hlsarna wks, max scrap	11,362	14.02	14.63	8.27	19.79	19.50	8.30	19.50	19.50
7bs	Hlsarna wks, max scrap (BAT)	11,362	12.97	13.16	7.13	18.66	18.03	6.82	18.03	18.03
8	Hlsarna wks, MDEA sep.	11,362	18.82	22.02	13.20	28.06	27.70	13.26	27.70	27.70
8b	Hlsarna wks, MDEA sep. (BAT)	11,362	17.62	20.38	11.96	26.82	26.06	11.62	26.06	26.06
8s	Hlsarna wks, max scrap, MDEA sep.	11,362	15.44	18.58	12.21	23.74	23.44	12.24	23.44	23.44
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	11,362	14.32	17.04	11.00	22.53	21.90	10.70	21.90	21.90
8.v	Hlsarna wks, VPSA sep.	11,362	18.74	21.33	12.50	27.37	27.01	12.57	27.01	27.01
8b.v	Hlsarna wks, VPSA sep. (BAT)	11,362	17.54	19.68	11.26	26.12	25.36	10.92	25.36	25.36
8s.v	Hlsarna wks, max scrap, VPSA sep.	11,362	15.38	18.04	11.67	23.20	22.90	11.70	22.90	22.90
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	11,362	14.26	16.50	10.47	21.99	21.36	10.16	21.36	21.36
9	MIDREX wks	11,362	14.55	14.87	16.70	17.00	17.00	16.70	17.00	17.00
9g	MIDREX gnf.wks	11,362	14.16	14.48	16.24	16.59	16.59	16.24	16.59	16.59
9b	MIDREX wks (BAT)	11,362	13.04	13.35	14.95	15.33	15.33	14.95	15.33	15.33
9.i	MIDREX wks, imp.elec.	11,362	12.68	17.01	18.84	19.14	19.14	18.84	19.14	19.14
9g.i	MIDREX gnf.wks, imp.elec.	11,362	12.60	16.95	18.71	19.06	19.06	18.71	19.06	19.06
9b.i	MIDREX wks, imp.elec. (BAT)	11,362	11.59	15.00	16.61	16.98	16.98	16.61	16.98	16.98
10	MIDREX wks MDEA sep.	11,362	16.60	16.91	18.74	19.04	19.04	18.74	19.04	19.04
10g	MIDREX gnf.wks MDEA sep.	11,362	16.20	16.52	18.28	18.63	18.63	18.28	18.63	18.63
10b	MIDREX wks MDEA sep. (BAT)	11,362	14.89	15.21	16.81	17.19	17.19	16.81	17.19	17.19
10.v	MIDREX wks VPSA sep.	11,362	15.50	15.82	17.65	17.95	17.95	17.65	17.95	17.95
10g.v	MIDREX gnf.wks VPSA sep.	11,362	15.11	15.43	17.19	17.54	17.54	17.19	17.54	17.54
10b.v	MIDREX wks VPSA sep. (BAT)	11,362	13.90	14.21	15.82	16.19	16.19	15.82	16.19	16.19
11	ULCORED wks, NG, MDEA sep.	11,362	15.36	15.67	18.02	18.32	18.32	18.02	18.32	18.32
11g	ULCORED gnf.wks, NG, MDEA sep.	11,362	14.96	15.27	17.55	17.90	17.90	17.55	17.90	17.90
11b	ULCORED wks, NG, MDEA sep. (BAT)	11,362	13.64	13.95	16.08	16.45	16.45	16.08	16.45	16.45
11.v	ULCORED wks, NG, VPSA sep.	11,362	14.32	14.63	16.98	17.28	17.28	16.98	17.28	17.28
11g.v	ULCORED gnf.wks, NG, VPSA sep.	11,362	13.92	14.24	16.52	16.87	16.87	16.52	16.87	16.87
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	11,362	12.71	13.02	15.14	15.52	15.52	15.14	15.52	15.52
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	11,362	13.07	18.28	20.63	20.93	20.93	20.63	20.93	20.93
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	11,362	12.69	17.87	20.15	20.50	20.50	20.15	20.50	20.50
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	11,362	11.81	16.05	18.17	18.54	18.54	18.17	18.54	18.54
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	11,362	11.89	17.41	19.76	20.06	20.06	19.76	20.06	20.06
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	11,362	11.51	17.00	19.28	19.63	19.63	19.28	19.63	19.63
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	11,362	10.74	15.27	17.39	17.76	17.76	17.39	17.76	17.76
12	ULCORED wks, coal, MDEA sep.	11,362	21.54	21.85	16.16	26.32	26.06	15.91	26.06	26.06
12g	ULCORED gnf.wks, coal, MDEA sep.	11,362	21.28	21.60	15.84	26.04	25.79	15.58	25.79	25.79
12b	ULCORED wks, coal, MDEA sep. (BAT)	11,362	19.82	20.14	14.22	24.45	24.20	13.97	24.20	24.20
12.v	ULCORED wks, coal, VPSA sep.	11,362	19.38	19.69	14.00	24.16	23.90	13.75	23.90	23.90
12g.v	ULCORED gnf.wks, coal, VPSA sep.	11,362	18.99	19.30	13.54	23.74	23.49	13.29	23.49	23.49
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	11,362	17.77	18.08	12.17	22.40	22.14	11.91	22.14	22.14
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	11,362	18.84	24.94	19.25	29.40	29.15	18.99	29.15	29.15
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	11,362	18.58	24.69	18.93	29.13	28.88	18.67	28.88	28.88
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	11,362	17.58	22.70	16.79	27.02	26.76	16.53	26.76	26.76
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	11,362	16.37	23.13	17.44	27.60	27.34	17.19	27.34	27.34
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	11,362	15.99	22.72	16.96	27.17	26.91	16.71	26.91	26.91
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	11,362	15.23	20.98	15.07	25.30	25.04	14.82	25.04	25.04
13	ULCORED wks, exs coal syng., MDEA sep.	11,362	32.45	32.76	23.54	44.97	39.18	17.75	39.18	39.18
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	11,362	32.20	32.52	23.22	44.70	38.91	17.43	38.91	38.91
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	11,362	30.71	31.03	21.58	43.08	37.29	15.79	37.29	37.29
13.v	ULCORED wks, exs coal syng., VPSA sep.	11,362	29.82	30.13	20.90	42.33	36.54	15.11	36.54	36.54
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	11,362	29.36	29.68	20.38	41.86	36.07	14.59	36.07	36.07
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	11,362	27.82	28.13	18.68	40.18	34.39	12.89	34.39	34.39
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	11,362	29.00	36.71	27.49	48.92	43.13	21.69	43.13	43.13
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	11,362	28.75	36.47	27.17	48.65	42.86	21.38	42.86	42.86
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	11,362	27.72	34.45	25.00	46.51	40.72	19.21	40.72	40.72
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	11,362	25.49	31.62	22.40	43.83	38.04	16.61	38.04	38.04
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	11,362	25.32	31.07	21.78	43.26	37.47	15.99	37.47	37.47
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	11,362	24.63	29.23	19.78	41.29	35.49	13.99	35.49	35.49
14	ULCORED wks, bio., MDEA sep.	11,362	17.76	18.07	15.27	22.25	22.00	15.02	22.00	22.00
14g	ULCORED gnf.wks, bio., MDEA sep.	11,362	17.52	17.84	14.97	22.00	21.74	14.72	21.74	21.74
14b	ULCORED wks, bio., MDEA sep. (BAT)	11,362	16.04	16.35	13.33	20.39	20.13	13.08	20.13	20.13
14.v	ULCORED wks, bio., VPSA sep.	11,362	15.67	15.98	13.18	20.16	19.91	12.93	19.91	19.91
14g.v	ULCORED gnf.wks, bio., VPSA sep.	11,362	15.53	15.84	12.97	20.00	19.75	12.72	19.75	19.75
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	11,362	14.31	14.62	11.60	18.66	18.40	11.35	18.40	18.40
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	11,362	15.14	21.07	18.27	25.25	25.00	18.01	25.00	25.00
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	11,362	14.90	20.84	17.97	25.00	24.75	17.72	24.75	24.75
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	11,362	13.88	18.83	15.81	22.86	22.61	15.55	22.61	22.61
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	11,362	13.04	19.54	16.73	23.72	23.46	16.48	23.46	23.46
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	11,362	12.66	19.13	16.26	23.29	23.03	16.00	23.03	23.03
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	11,362	11.90	17.39	14.36	21.42	21.16	14.11	21.16	21.16
15	ULCORED wks, exs bio.syng., MDEA sep.	11,362	23.64	23.95	20.92	35.55	29.76	15.13	29.76	29.76
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	11,362	24.00	24.32	21.22	35.89	30.10	15.43	30.10	30.10
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	11,362	22.49	22.80	19.55	34.25	28.46	13.76	28.46	28.46
15.v	ULCORED wks, exs bio.syng., VPSA sep.	11,362	22.23	22.54	19.51	34.14	28.35	13.72	28.35	28.35
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	11,362	21.12	21.43	18.33	33.01	27.22	12.54	27.22	27.22
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	11,362	19.95	20.27	17.01	31.71	25.92	11.22	25.92	25.92
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	11,362	20.94	28.30	25.27	39.90	34.11	19.48	34.11	34.11
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	11,362	20.71	28.09	24.99	39.66	33.87	19.20	33.87	33.87
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	11,362	19.66	26.04	22.79	37.49	31.70	17.00	31.70	31.70
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	11,362	18.34	23.89	20.86	35.48	29.69	15.07	29.69	29.69
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	11,362	18.13	23.25	20.15	34.83	29.04	14.36	29.04	29.04
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	11,362	17.35	21.16	17.91	32.61	26.82	12.12	26.82	26.82
16	ULCOWIN wks, imp.elec.	11,362	15.56	36.73	39.90	40.20	40.20	39.90	40.20	40.20
16g	ULCOWIN gnf.wks, imp.elec.	11,362	15.12	36.22	39.32	39.67	39.67	39.32	39.67	39.67
16b	ULCOWIN wks, imp.elec. (BAT)	11,362	14.26	34.34	37.28	37.65	37.65	37.28	37.65	37.65

Table A-20: Energy intensities of technology sites constructed for the UK iron and steel sector

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ID	Description	Output	SEC	SEC_p	PER - Scope I	GER - Scope I	NER - Scope I	PER - Scope II	GER - Scope II	NER - Scope II
		kt	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	11,362	20.50	22.60	23.71	43.98	27.01	13.09	27.31	27.01
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	11,362	17.42	19.31	21.00	40.98	23.60	9.97	23.90	23.60
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	11,362	16.91	18.70	20.04	35.76	22.58	11.78	22.81	22.58
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	11,362	14.35	15.96	17.77	33.26	19.74	9.17	19.98	19.74
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	11,362	18.41	20.93	22.04	42.31	25.34	11.41	25.64	25.34
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	11,362	15.54	17.85	19.54	39.51	22.13	8.51	22.44	22.13
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	11,362	15.28	17.40	18.73	34.45	21.27	10.47	21.50	21.27
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	11,362	12.72	14.66	16.47	31.96	18.44	7.87	18.68	18.44
6.2	TGR-BF [V4] wks, MDEA sep.	11,362	20.50	22.60	23.71	43.98	27.01	13.09	27.31	27.01
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	11,362	17.42	19.31	21.00	40.98	23.60	9.97	23.90	23.60
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	11,362	16.91	18.70	20.04	35.76	22.58	11.78	22.81	22.58
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	11,362	14.35	15.96	17.77	33.26	19.74	9.17	19.98	19.74
6.2.v	TGR-BF [V4] wks, VPSA sep.	11,362	18.41	20.93	22.04	42.31	25.34	11.41	25.64	25.34
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	11,362	15.54	17.85	19.54	39.51	22.13	8.51	22.44	22.13
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	11,362	15.28	17.40	18.73	34.45	21.27	10.47	21.50	21.27
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	11,362	12.72	14.66	16.47	31.96	18.44	7.87	18.68	18.44
7	Hlsarna wks	11,362	17.87	18.03	7.04	22.62	22.26	7.10	22.26	22.26
7b	Hlsarna wks (BAT)	11,362	16.75	16.45	5.86	21.45	20.68	5.52	20.68	20.68
7s	Hlsarna wks, max scrap	11,362	14.58	15.19	7.14	19.23	18.94	7.18	18.94	18.94
7bs	Hlsarna wks, max scrap (BAT)	11,362	13.53	13.72	6.01	18.09	17.47	5.70	17.47	17.47
8	Hlsarna wks, MDEA sep.	11,362	19.60	22.93	11.94	27.53	27.17	12.00	27.17	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	11,362	18.40	21.29	10.70	26.29	25.53	10.36	25.53	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	11,362	16.05	19.28	11.23	23.32	23.03	11.27	23.03	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	11,362	14.93	17.75	10.03	22.12	21.49	9.72	21.49	21.49
8.v	Hlsarna wks, VPSA sep.	11,362	19.52	22.20	11.21	26.79	26.44	11.27	26.44	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	11,362	18.32	20.55	9.97	25.55	24.79	9.62	24.79	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	11,362	15.98	18.71	10.67	22.75	22.46	10.70	22.46	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	11,362	14.86	17.18	9.46	21.55	20.92	9.16	20.92	20.92
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	11,362	20.50	22.60	23.71	43.98	27.01	13.09	27.31	27.01
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	11,362	17.42	19.31	21.00	40.98	23.60	9.97	23.90	23.60
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	11,362	16.91	18.70	20.04	35.76	22.58	11.78	22.81	22.58
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	11,362	14.35	15.96	17.77	33.26	19.74	9.17	19.98	19.74
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	11,362	18.41	20.93	22.04	42.31	25.34	11.41	25.64	25.34
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	11,362	15.54	17.85	19.54	39.51	22.13	8.51	22.44	22.13
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	11,362	15.28	17.40	18.73	34.45	21.27	10.47	21.50	21.27
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	11,362	12.72	14.66	16.47	31.96	18.44	7.87	18.68	18.44
8	Hlsarna wks, MDEA sep.	11,362	19.60	22.93	11.94	27.53	27.17	12.00	27.17	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	11,362	18.40	21.29	10.70	26.29	25.53	10.36	25.53	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	11,362	16.05	19.28	11.23	23.32	23.03	11.27	23.03	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	11,362	14.93	17.75	10.03	22.12	21.49	9.72	21.49	21.49
8.v	Hlsarna wks, VPSA sep.	11,362	19.52	22.20	11.21	26.79	26.44	11.27	26.44	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	11,362	18.32	20.55	9.97	25.55	24.79	9.62	24.79	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	11,362	15.98	18.71	10.67	22.75	22.46	10.70	22.46	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	11,362	14.86	17.18	9.46	21.55	20.92	9.16	20.92	20.92
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	11,362	20.50	22.60	23.71	43.98	27.01	13.09	27.31	27.01
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	11,362	17.42	19.31	21.00	40.98	23.60	9.97	23.90	23.60
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	11,362	16.91	18.70	20.04	35.76	22.58	11.78	22.81	22.58
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	11,362	14.35	15.96	17.77	33.26	19.74	9.17	19.98	19.74
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	11,362	18.41	20.93	22.04	42.31	25.34	11.41	25.64	25.34
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	11,362	15.54	17.85	19.54	39.51	22.13	8.51	22.44	22.13
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	11,362	15.28	17.40	18.73	34.45	21.27	10.47	21.50	21.27
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	11,362	12.72	14.66	16.47	31.96	18.44	7.87	18.68	18.44
8	Hlsarna wks, MDEA sep.	11,362	19.60	22.93	11.94	27.53	27.17	12.00	27.17	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	11,362	18.40	21.29	10.70	26.29	25.53	10.36	25.53	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	11,362	16.05	19.28	11.23	23.32	23.03	11.27	23.03	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	11,362	14.93	17.75	10.03	22.12	21.49	9.72	21.49	21.49
8.v	Hlsarna wks, VPSA sep.	11,362	19.52	22.20	11.21	26.79	26.44	11.27	26.44	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	11,362	18.32	20.55	9.97	25.55	24.79	9.62	24.79	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	11,362	15.98	18.71	10.67	22.75	22.46	10.70	22.46	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	11,362	14.86	17.18	9.46	21.55	20.92	9.16	20.92	20.92

Table A-21: Energy intensities of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description										85% Grid decarb.	
		Carbon fixation	SE_1	SE_2	PRE - Scope I	GRE - Scope I	NRE - Scope I	PRE - Scope II	GRE - Scope II	NRE - Scope II	SE_2	NRE
		$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$
0	Sector (Base)		1,650	1,824	1,964	4,618	2,174	628	2,213	2,174	1,676	1,903
0p	Sector (TP)		1,527	1,654	1,912	4,381	1,992	527	2,025	1,992	1,546	1,771
0p2	Sector (TP2)		1,525	1,644	1,902	4,370	1,981	517	2,013	1,981	1,543	1,767
0b	Sector (BAT)		1,513	1,574	1,772	4,161	1,909	444	1,939	1,909	1,522	1,744
1	Int.wks (Base)		2,040	2,160	2,296	5,642	2,551	603	2,599	2,551	2,058	2,305
1p	Int.wks (TP)		1,890	1,963	2,245	5,361	2,339	1,107	2,379	2,339	1,901	2,146
1b	Int.wks (BAT)		1,882	1,884	2,095	5,107	2,258	1,084	2,296	2,258	1,882	2,126
1s	Int.wks max scrap		1,635	1,747	1,898	4,495	2,091	581	2,128	2,091	1,652	1,874
1bs	Int.wks max scrap (BAT)		1,505	1,510	1,723	4,060	1,841	931	1,870	1,841	1,506	1,728
2	EAF wks (Base)		184	561	719	775	762	719	762	762	241	394
2p2	EAF wks (TP2)		156	446	601	651	639	601	639	639	199	345
2p	EAF wks (TP)		161	492	650	705	693	650	693	693	211	364
2b	EAF wks (BAT)		129	411	557	610	599	557	599	599	171	313
3g	EAF gnf.wks		154	501	666	721	710	666	710	710	206	370
3gb	EAF gnf.wks (BAT)		136	399	554	607	595	554	595	595	175	327
4	Int.wks, MEA sep.		956	1,169	2,712	6,058	1,559	1,018	1,606	1,559	988	1,234
4b	Int.wks, MEA sep. (BAT)		636	791	2,406	5,419	1,161	724	1,199	1,161	659	903
4s	Int.wks, max scrap, MEA sep.		781	965	2,227	4,822	1,310	909	1,346	1,310	809	1,031
4bs	Int.wks, max scrap, MEA sep. (BAT)		563	697	1,978	4,315	1,026	666	1,055	1,026	583	802
5	TGR-BF wks, MDEA sep. w/o storage		1,881	2,073	2,355	5,051	2,430	843	2,465	2,430	1,909	2,144
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)		1,702	1,865	2,257	4,919	2,216	662	2,252	2,216	1,727	1,961
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage		1,511	1,674	1,939	4,032	1,993	763	2,021	1,993	1,536	1,748
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)		1,366	1,503	1,857	3,924	1,817	613	1,845	1,817	1,387	1,599
5.v	TGR-BF wks, VPSA sep. w/o storage		1,747	1,977	2,259	4,955	2,334	747	2,370	2,334	1,781	2,016
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)		1,583	1,783	2,175	4,837	2,135	581	2,170	2,135	1,613	1,847
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage		1,407	1,600	1,864	3,957	1,918	688	1,946	1,918	1,436	1,648
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)		1,262	1,429	1,783	3,849	1,743	538	1,770	1,743	1,287	1,500
6	TGR-BF wks, MDEA sep.		1,128	1,320	2,355	5,051	1,677	843	1,713	1,677	1,157	1,391
6b	TGR-BF wks, MDEA sep. (BAT)		950	1,112	2,257	4,919	1,464	662	1,499	1,464	974	1,208
6s	TGR-BF wks, max scrap, MDEA sep.		928	1,091	1,939	4,032	1,409	763	1,437	1,409	952	1,165
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)		783	920	1,857	3,924	1,234	613	1,261	1,234	803	1,016
6.v	TGR-BF wks, VPSA sep.		994	1,224	2,259	4,955	1,581	747	1,617	1,581	1,029	1,263
6b.v	TGR-BF wks, VPSA sep. (BAT)		831	1,031	2,175	4,837	1,382	581	1,418	1,382	861	1,095
6s.v	TGR-BF wks, max scrap, VPSA sep.		823	1,016	1,864	3,957	1,335	688	1,362	1,335	852	1,065
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)		679	845	1,783	3,849	1,159	538	1,187	1,159	704	916
7	HIsarna wks		1,563	1,577	640	2,238	1,987	550	1,987	1,987	1,565	1,866
7b	HIsarna wks (BAT)		1,515	1,515	660	2,257	1,924	487	1,924	1,924	1,515	1,815
7s	HIsarna wks, max scrap		1,236	1,291	610	1,851	1,651	537	1,651	1,651	1,244	1,508
7bs	HIsarna wks, max scrap (BAT)		1,190	1,208	595	1,835	1,567	453	1,567	1,567	1,193	1,457
8	HIsarna wks, MDEA sep.		439	731	907	2,505	1,141	816	1,141	1,141	483	784
8b	HIsarna wks, MDEA sep. (BAT)		387	637	896	2,494	1,047	723	1,047	1,047	424	725
8s	HIsarna wks, max scrap, MDEA sep.		365	651	834	2,075	1,010	760	1,010	1,010	408	673
8bs	HIsarna wks, max scrap, MDEA sep. (BAT)		316	564	814	2,054	923	672	923	923	353	617
8.v	HIsarna wks, VPSA sep.		456	692	868	2,466	1,102	777	1,102	1,102	491	793
8b.v	HIsarna wks, VPSA sep. (BAT)		403	598	857	2,454	1,008	683	1,008	1,008	433	733
8s.v	HIsarna wks, max scrap, VPSA sep.		379	621	803	2,044	980	729	980	980	415	679
8bs.v	HIsarna wks, max scrap, VPSA sep. (BAT)		329	533	784	2,024	892	642	892	892	360	624
9	MIDREX wks		841	870	1,018	1,114	1,055	1,018	1,055	1,055	846	964
9g	MIDREX gnf.wks		818	846	992	1,088	1,030	992	1,030	1,030	822	942
9b	MIDREX wks (BAT)		749	778	918	1,012	954	918	954	954	753	866
9.i	MIDREX wks, imp.elec.		595	989	1,137	1,233	1,174	1,137	1,174	1,174	654	772
9g.i	MIDREX gnf.wks, imp.elec.		588	984	1,129	1,226	1,167	1,129	1,167	1,167	647	767
9b.i	MIDREX wks, imp.elec. (BAT)		559	869	1,010	1,104	1,046	1,010	1,046	1,046	605	718
10	MIDREX wks MDEA sep.		401	430	1,135	1,231	615	1,135	615	615	406	524
10g	MIDREX gnf.wks MDEA sep.		379	407	1,108	1,204	591	1,108	591	591	383	503
10b	MIDREX wks MDEA sep. (BAT)		349	377	1,024	1,118	554	1,024	554	554	353	465
10.v	MIDREX wks VPSA sep.		321	350	1,072	1,168	535	1,072	535	535	325	444
10g.v	MIDREX gnf.wks VPSA sep.		299	328	1,046	1,142	511	1,046	511	511	303	423
10b.v	MIDREX wks VPSA sep. (BAT)		276	305	968	1,061	481	968	481	481	280	393
11	ULCORED wks, NG, MDEA sep.		358	386	1,093	1,189	601	1,093	601	601	362	510
11g	ULCORED gnf.wks, NG, MDEA sep.		335	364	1,066	1,163	577	1,066	577	577	340	489
11b	ULCORED wks, NG, MDEA sep. (BAT)		308	337	982	1,076	542	982	542	542	312	454
11.v	ULCORED wks, NG, VPSA sep.		281	309	1,034	1,130	524	1,034	524	524	285	433
11g.v	ULCORED gnf.wks, NG, VPSA sep.		259	287	1,007	1,103	500	1,007	500	500	263	412
11b.v	ULCORED wks, NG, VPSA sep. (BAT)		239	267	929	1,022	473	929	473	473	243	385
11.i	ULCORED wks, imp.elec., NG, MDEA sep.		327	801	1,238	1,334	1,016	1,238	1,016	1,016	398	546
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.		305	776	1,210	1,306	989	1,210	989	989	376	525
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)		284	669	1,098	1,192	875	1,098	875	875	341	483
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.		248	751	1,188	1,284	966	1,188	966	966	324	472
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.		226	726	1,160	1,257	940	1,160	940	940	301	450
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)		213	624	1,053	1,147	830	1,053	830	830	274	416
12	ULCORED wks, coal, MDEA sep.		521	550	977	2,019	858	977	858	858	525	749
12g	ULCORED gnf.wks, coal, MDEA sep.		468	497	958	2,000	804	958	804	804	473	697
12b	ULCORED wks, coal, MDEA sep. (BAT)		471	500	866	1,905	799	866	799	799	475	693
12.v	ULCORED wks, coal, VPSA sep.		361	389	854	1,895	698	854	698	698	365	589
12g.v	ULCORED gnf.wks, coal, VPSA sep.		339	367	827	1,869	674	827	674	674	343	568
12b.v	ULCORED wks, coal, VPSA sep. (BAT)		319	347	749	1,788	647	749	647	647	323	540
12.i	ULCORED wks, imp.elec., coal, MDEA sep.		485	1,039	1,148	2,190	1,348	1,148	1,348	1,348	568	792
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.		468	1,023	1,129	2,171	1,330	1,129	1,330	1,330	552	776
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)		441	907	1,008	2,047	1,207	1,008	1,207	1,207	511	728
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.		320	936	1,044	2,086	1,244	1,044	1,244	1,244	413	636
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.		299	911	1,017	2,058	1,218	1,017	1,218	1,218	390	615
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)		285	808	909	1,948	1,108	909	1,108	1,108	363	581
13	ULCORED wks, exs coal syng., MDEA sep.		549	578	1,087	3,210	1,017	1,087	1,017	1,017	553	887
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.		497	525	1,069	3,192	963	1,069	963	963	501	836
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)		498	526	975	3,096	957	975	957	957	502	830
13.v	ULCORED wks, exs coal syng., VPSA sep.		403	431	937	3,060	871	937	871	871	407	741
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.		401	429	907	3,030	867	907	867	867	405	740
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)		389	418	809	2,930	848	809	848	848	394	721
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.		503	1,204	1,306	3,429	1,644	1,306	1,644	1,644	608	942
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.		487	1,189	1,288	3,411	1,627	1,288	1,627	1,627	592	927
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)		458	1,071	1,165	3,286	1,501	1,165	1,501	1,501	550	877
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.		357	915	1,017	3,140	1,354	1,017	1,354	1,354	441	775
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.		359	882	981	3,105	1,320	981	1,320	1,320	437	772
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)		356	774	868	2,989	1,205	868	1,205	1,205	418	746
14	ULCORED wks, bio., MDEA sep.	766	472	501	921	1,783	788	921	788	788	477	697
14g	ULCORED gnf.wks, bio., MDEA sep.	766	415	444	904	1,766	729	904	729	729	419	641
14b	ULCORED wks, bio., MDEA sep. (BAT)	766	423	451	810	1,670	730	810	730	730	427	641
14.v	ULCORED wks, bio., VPSA sep.	766	322	350	802	1,664	638	802	638	638	326	547
14g.v	ULCORED gnf.wks, bio., VPSA sep.	766	314	343	790	1,652	629	790	629	629	318	540
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	766	294	323	711	1,571	601	711	601	601	299	513
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	766	437	977	1,087	1,949	1,264	1,087	1,264	1,264	518	739
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	766	422	963	1,070	1,932	1,248	1,070	1,248	1,248	503	725
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	766	394	845	948	1,807	1,123	948	1,123	1,123	461	676
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	766	298	889	999	1,861	1,176	999	1,176	1,176	386	607
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	766	276	864	972	1,834	1,150	972	1,150	1,150	364	586
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	766	262	761	864	1,724	1,040	864	1,040	1,040	337	551
15	ULCORED wks, exs bio.syng., MDEA sep.	1,642	404	433	927	2,666	827	927	827	827	409	736
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	1,642	381	410	944	2,682	802	944	802	802	385	714
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	1,642	387	416	849	2,584	801	849	801	801	391	712
15.v	ULCORED wks, exs bio.syng., VPSA sep.	1,642	349	378	847	2,585	772	847	772	772	353	681
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	1,642	344	372	779	2,517	765	779	765	765	348	677
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	1,642	334	363	704	2,439	748	704	748	748	339	660
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	1,642	394	1,064	1,169	2,908	1,458	1,169	1,458	1,458	494	822
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	1,642	379	1,050	1,153	2,891	1,443	1,153	1,443	1,443	480	808
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	1,642	349	930	1,028	2,764	1,315	1,028	1,315	1,315	436	757
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	1,642	309	813	919	2,657	1,207	919	1,207	1,207	384	712
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	1,642	309	776	879	2,617	1,168	879	1,168	1,168	379	708
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	1,642	307	654	752	2,488	1,039	752	1,039	1,039	359	680
16	ULCOWIN wks, imp.elec.		173	2,099	2,328	2,530	2,365	2,328	2,365	2,365	462	648
16g	ULCOWIN gnf.wks, imp.elec.		149	2,069	2,295	2,497	2,333	2,295	2,333	2,333	437	624
16b	ULCOWIN wks, imp.elec. (BAT)		131	1,958	2,180	2,379	2,214	2,180	2,214	2,214	405	585

Table A-22: GhG emissions intensities of technology sites constructed for the UK iron and steel sector

ID	Description										85% Grid decarb.	
		Carbon fixation	SE_1	SE_2	PRE - Scope I	GRE - Scope I	NRE - Scope I	PRE - Scope II	GRE - Scope II	NRE - Scope II	SE_2	NRE
		$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$	$kgCO_2e/tc$
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage		1,723	1,914	2,331	4,624	2,260	840	2,287	2,260	1,751	1,977
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)		1,538	1,710	2,237	4,497	2,050	664	2,077	2,050	1,564	1,790
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage		1,388	1,551	1,920	3,700	1,860	760	1,881	1,860	1,412	1,618
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)		1,235	1,382	1,841	3,594	1,687	612	1,708	1,687	1,257	1,463
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage		1,589	1,818	2,235	4,528	2,164	744	2,191	2,164	1,623	1,849
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)		1,416	1,626	2,153	4,413	1,966	580	1,993	1,966	1,448	1,673
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage		1,283	1,476	1,845	3,625	1,785	685	1,806	1,785	1,312	1,518
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)		1,131	1,307	1,766	3,520	1,612	538	1,633	1,612	1,157	1,363
6.2	TGR-BF [V4] wks, MDEA sep.		970	1,162	2,331	4,624	1,508	840	1,534	1,508	999	1,225
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)		786	958	2,237	4,497	1,298	664	1,325	1,298	811	1,037
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.		804	967	1,920	3,700	1,277	760	1,297	1,277	828	1,035
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)		651	798	1,841	3,594	1,104	612	1,124	1,104	673	879
6.2.v	TGR-BF [V4] wks, VPSA sep.		836	1,066	2,235	4,528	1,412	744	1,438	1,412	871	1,097
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)		664	874	2,153	4,413	1,214	580	1,241	1,214	695	921
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.		700	892	1,845	3,625	1,202	685	1,223	1,202	729	935
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)		547	724	1,766	3,520	1,029	538	1,050	1,029	574	780
7	Hlsarna wks	1,455	1,632	1,647	550	2,217	1,967	460	1,967	1,967	1,635	3,327
7b	Hlsarna wks (BAT)	1,455	1,584	1,584	570	2,236	1,903	397	1,903	1,903	1,584	3,276
7s	Hlsarna wks, max scrap	1,128	1,289	1,345	541	1,836	1,635	467	1,635	1,635	1,298	2,641
7bs	Hlsarna wks, max scrap (BAT)	1,128	1,244	1,262	525	1,819	1,551	383	1,551	1,551	1,247	2,590
8	Hlsarna wks, MDEA sep.	1,455	447	750	828	2,495	1,070	737	1,070	1,070	493	2,185
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	657	817	2,484	977	644	977	977	434	2,126
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	666	772	2,067	956	698	956	956	416	1,759
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	579	753	2,046	868	611	868	868	360	1,704
8.v	Hlsarna wks, VPSA sep.	1,455	465	709	786	2,454	1,029	696	1,029	1,029	502	2,194
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	616	776	2,442	935	602	935	935	443	2,135
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	634	740	2,035	924	666	924	924	423	1,766
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	547	721	2,014	836	579	836	836	367	1,711
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]		1,723	1,914	2,331	4,624	2,260	840	2,287	2,260	1,751	1,977
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)		1,538	1,710	2,237	4,497	2,050	664	2,077	2,050	1,564	1,790
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]		1,388	1,551	1,920	3,700	1,860	760	1,881	1,860	1,412	1,618
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)		1,235	1,382	1,841	3,594	1,687	612	1,708	1,687	1,257	1,463
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]		1,589	1,818	2,235	4,528	2,164	744	2,191	2,164	1,623	1,849
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)		1,416	1,626	2,153	4,413	1,966	580	1,993	1,966	1,448	1,673
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]		1,283	1,476	1,845	3,625	1,785	685	1,806	1,785	1,312	1,518
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)		1,131	1,307	1,766	3,520	1,612	538	1,633	1,612	1,157	1,363
8	Hlsarna wks, MDEA sep.	1,455	447	750	828	2,495	1,070	737	1,070	1,070	493	2,185
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	657	817	2,484	977	644	977	977	434	2,126
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	666	772	2,067	956	698	956	956	416	1,759
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	579	753	2,046	868	611	868	868	360	1,704
8.v	Hlsarna wks, VPSA sep.	1,455	465	709	786	2,454	1,029	696	1,029	1,029	502	2,194
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	616	776	2,442	935	602	935	935	443	2,135
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	634	740	2,035	924	666	924	924	423	1,766
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	547	721	2,014	836	579	836	836	367	1,711
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]		1,723	1,914	2,331	4,624	2,260	840	2,287	2,260	1,751	1,977
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)		1,538	1,710	2,237	4,497	2,050	664	2,077	2,050	1,564	1,790
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]		1,388	1,551	1,920	3,700	1,860	760	1,881	1,860	1,412	1,618
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)		1,235	1,382	1,841	3,594	1,687	612	1,708	1,687	1,257	1,463
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]		1,589	1,818	2,235	4,528	2,164	744	2,191	2,164	1,623	1,849
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)		1,416	1,626	2,153	4,413	1,966	580	1,993	1,966	1,448	1,673
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]		1,283	1,476	1,845	3,625	1,785	685	1,806	1,785	1,312	1,518
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)		1,131	1,307	1,766	3,520	1,612	538	1,633	1,612	1,157	1,363
8	Hlsarna wks, MDEA sep.	1,455	447	750	828	2,495	1,070	737	1,070	1,070	493	2,185
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	657	817	2,484	977	644	977	977	434	2,126
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	666	772	2,067	956	698	956	956	416	1,759
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	579	753	2,046	868	611	868	868	360	1,704
8.v	Hlsarna wks, VPSA sep.	1,455	465	709	786	2,454	1,029	696	1,029	1,029	502	2,194
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	616	776	2,442	935	602	935	935	443	2,135
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	634	740	2,035	924	666	924	924	423	1,766
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	547	721	2,014	836	579	836	836	367	1,711

Table A-23: GhG emissions intensities of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	SE₂ (2010; 2023 Grid EF: 38% decarb. from	SE₂ (2020; 2023 Grid EF: 66% decarb. from	SE₂ (2030; 2023 Grid EF: 78% decarb. from	SE₂ (2040; 2023 Grid EF: 85% decarb. from	SE₂ (2050; 2023 Grid EF: 85% decarb. from	Abatement (2010)	Abatement (2020)	Abatement (2030)	Abatement (2040)	Abatement (2050)
		$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$
0	Sector (Base)	1,758	1,711	1,688	1,676	1,676					
0p	Sector (TP)	1,606	1,571	1,554	1,546	1,546	152	139	133	130	130
0p2	Sector (TP2)	1,599	1,567	1,551	1,543	1,543	159	144	136	132	132
0b	Sector (BAT)	1,551	1,534	1,526	1,522	1,522	207	176	162	154	154
1	Int.wks (Base)	2,115	2,082	2,067	2,058	2,058					
1p	Int.wks (TP)	1,936	1,916	1,906	1,901	1,901	179	168	160	157	157
1b	Int.wks (BAT)	1,883	1,883	1,882	1,882	1,882	232	200	184	176	176
1s	Int.wks max scrap	1,705	1,674	1,660	1,652	1,652	410	408	407	406	406
1bs	Int.wks max scrap (BAT)	1,508	1,507	1,506	1,506	1,506	607	576	561	553	553
2	EAF wks (Base)	418	316	267	241	241					
2p2	EAF wks (TP2)	336	257	219	199	199	82.37	58.91	47.67	41.65	41.65
2p	EAF wks (TP)	367	277	234	211	211	51.45	39.22	33.36	30.23	30.23
2b	EAF wks (BAT)	304	227	191	171	171	114	88.52	76.27	69.72	69.72
3g	EAF gnf.wks	370	275	230	206	206	1,745	1,807	1,836	1,852	1,852
3gb	EAF gnf.wks (BAT)	299	228	194	175	175	1,816	1,854	1,873	1,883	1,883
4	Int.wks, MEA sep.	1,088	1,030	1,002	988	988	1,027	1,052	1,064	1,071	1,071
4b	Int.wks, MEA sep. (BAT)	732	690	670	659	659	1,383	1,392	1,397	1,399	1,399
4s	Int.wks, max scrap, MEA sep.	896	846	822	809	809	1,219	1,237	1,245	1,249	1,249
4bs	Int.wks, max scrap, MEA sep. (BAT)	646	610	592	583	583	1,469	1,472	1,474	1,475	1,475
5	TGR-BF wks, MDEA sep. w/o storage	2,000	1,948	1,923	1,909	1,909	115	134	144	149	149
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	1,803	1,759	1,738	1,727	1,727	312	323	329	331	331
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	1,613	1,568	1,547	1,536	1,536	502	514	520	523	523
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	1,451	1,414	1,396	1,387	1,387	664	668	670	671	671
5.v	TGR-BF wks, VPSA sep. w/o storage	1,890	1,827	1,797	1,781	1,781	225	255	269	277	277
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	1,707	1,653	1,627	1,613	1,613	407	429	440	445	445
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	1,527	1,474	1,449	1,436	1,436	588	608	617	622	622
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	1,366	1,320	1,299	1,287	1,287	749	762	768	771	771
6	TGR-BF wks, MDEA sep.	1,248	1,195	1,170	1,157	1,157	867	887	896	901	901
6b	TGR-BF wks, MDEA sep. (BAT)	1,051	1,007	986	974	974	1,064	1,075	1,081	1,084	1,084
6s	TGR-BF wks, max scrap, MDEA sep.	1,029	985	963	952	952	1,086	1,097	1,103	1,106	1,106
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	868	831	813	803	803	1,247	1,252	1,254	1,255	1,255
6.v	TGR-BF wks, VPSA sep.	1,137	1,075	1,045	1,029	1,029	978	1,007	1,022	1,029	1,029
6b.v	TGR-BF wks, VPSA sep. (BAT)	955	901	875	861	861	1,160	1,182	1,192	1,197	1,197
6s.v	TGR-BF wks, max scrap, VPSA sep.	943	891	866	852	852	1,172	1,191	1,201	1,206	1,206
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	782	737	715	704	704	1,333	1,345	1,351	1,354	1,354
7	Hlsarna wks	1,572	1,568	1,566	1,565	1,565	543	514	500	493	493
7b	Hlsarna wks (BAT)	1,515	1,515	1,515	1,515	1,515	600	568	552	544	544
7s	Hlsarna wks, max scrap	1,270	1,255	1,248	1,244	1,244	845	827	819	814	814
7bs	Hlsarna wks, max scrap (BAT)	1,201	1,196	1,194	1,193	1,193	914	886	872	865	865
8	Hlsarna wks, MDEA sep.	620	541	503	483	483	1,494	1,541	1,563	1,575	1,575
8b	Hlsarna wks, MDEA sep. (BAT)	542	474	442	424	424	1,572	1,608	1,625	1,634	1,634
8s	Hlsarna wks, max scrap, MDEA sep.	543	465	428	408	408	1,572	1,617	1,638	1,650	1,650
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	470	402	370	353	353	1,645	1,680	1,696	1,705	1,705
8.v	Hlsarna wks, VPSA sep.	603	539	508	491	491	1,512	1,544	1,559	1,567	1,567
8b.v	Hlsarna wks, VPSA sep. (BAT)	524	472	446	433	433	1,590	1,611	1,620	1,626	1,626
8s.v	Hlsarna wks, max scrap, VPSA sep.	529	463	432	415	415	1,586	1,619	1,635	1,643	1,643
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	456	400	374	360	360	1,659	1,682	1,693	1,699	1,699
9	MIDREX wks	859	851	848	846	846	1,256	1,231	1,219	1,212	1,212
9g	MIDREX gnf.wks	835	828	824	822	822	1,279	1,254	1,243	1,236	1,236
9b	MIDREX wks (BAT)	767	759	755	753	753	1,348	1,323	1,311	1,305	1,305
9.i	MIDREX wks, imp.elec.	840	732	681	654	654	1,275	1,350	1,385	1,405	1,405
9g.i	MIDREX gnf.wks, imp.elec.	834	726	675	647	647	1,281	1,356	1,392	1,411	1,411
9b.i	MIDREX wks, imp.elec. (BAT)	752	667	627	605	605	1,363	1,415	1,440	1,453	1,453
10	MIDREX wks MDEA sep.	419	411	407	406	406	1,696	1,671	1,659	1,653	1,653
10g	MIDREX gnf.wks MDEA sep.	396	389	385	383	383	1,718	1,693	1,681	1,675	1,675
10b	MIDREX wks MDEA sep. (BAT)	367	359	355	353	353	1,748	1,723	1,711	1,705	1,705
10.v	MIDREX wks VPSA sep.	339	331	327	325	325	1,776	1,751	1,739	1,733	1,733
10g.v	MIDREX gnf.wks VPSA sep.	317	309	305	303	303	1,798	1,773	1,761	1,755	1,755
10b.v	MIDREX wks VPSA sep. (BAT)	294	286	282	280	280	1,821	1,796	1,784	1,778	1,778
11	ULCORED wks, NG, MDEA sep.	376	368	364	362	362	1,739	1,714	1,702	1,696	1,696
11g	ULCORED gnf.wks, NG, MDEA sep.	353	345	342	340	340	1,762	1,737	1,725	1,718	1,718
11b	ULCORED wks, NG, MDEA sep. (BAT)	326	318	314	312	312	1,789	1,764	1,752	1,746	1,746
11.v	ULCORED wks, NG, VPSA sep.	299	291	287	285	285	1,816	1,791	1,779	1,773	1,773
11g.v	ULCORED gnf.wks, NG, VPSA sep.	276	269	265	263	263	1,838	1,813	1,801	1,795	1,795
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	257	249	245	243	243	1,858	1,833	1,821	1,815	1,815
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	622	493	431	398	398	1,493	1,589	1,635	1,660	1,660
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	598	470	408	376	376	1,517	1,612	1,658	1,682	1,682
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	523	418	368	341	341	1,592	1,664	1,698	1,717	1,717
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	561	424	359	324	324	1,554	1,658	1,708	1,734	1,734
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	537	401	336	301	301	1,578	1,681	1,730	1,757	1,757
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	468	356	303	274	274	1,647	1,726	1,764	1,784	1,784
12	ULCORED wks, coal, MDEA sep.	539	531	527	525	525	1,576	1,551	1,539	1,533	1,533
12g	ULCORED gnf.wks, coal, MDEA sep.	486	478	475	473	473	1,629	1,604	1,592	1,585	1,585
12b	ULCORED wks, coal, MDEA sep. (BAT)	489	481	477	475	475	1,626	1,601	1,589	1,583	1,583
12.v	ULCORED wks, coal, VPSA sep.	379	371	367	365	365	1,736	1,711	1,699	1,693	1,693
12g.v	ULCORED gnf.wks, coal, VPSA sep.	356	349	345	343	343	1,758	1,734	1,722	1,715	1,715
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	337	329	325	323	323	1,778	1,753	1,741	1,735	1,735
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	829	679	607	568	568	1,286	1,403	1,460	1,490	1,490
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	813	662	590	552	552	1,302	1,420	1,476	1,507	1,507
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	731	604	543	511	511	1,384	1,478	1,523	1,547	1,547
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	703	536	455	413	413	1,412	1,547	1,611	1,645	1,645
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	679	513	433	390	390	1,436	1,570	1,634	1,668	1,668
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	610	468	400	363	363	1,505	1,614	1,667	1,695	1,695
13	ULCORED wks, exs coal syng., MDEA sep.	567	559	555	553	553	1,548	1,523	1,511	1,505	1,505
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	515	507	503	501	501	1,600	1,575	1,563	1,557	1,557
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	516	508	504	502	502	1,599	1,574	1,562	1,556	1,556
13.v	ULCORED wks, exs coal syng., VPSA sep.	421	413	409	407	407	1,694	1,669	1,657	1,651	1,651
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	419	411	407	405	405	1,696	1,671	1,659	1,653	1,653
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	407	399	396	394	394	1,708	1,683	1,671	1,665	1,665
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	939	748	657	608	608	1,176	1,334	1,410	1,450	1,450
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	923	732	641	592	592	1,192	1,350	1,426	1,466	1,466
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	838	672	592	550	550	1,276	1,410	1,474	1,509	1,509
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	704	552	479	441	441	1,411	1,530	1,587	1,617	1,617
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	684	542	473	437	437	1,431	1,541	1,593	1,621	1,621
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	616	502	447	418	418	1,499	1,580	1,619	1,640	1,640
14	ULCORED wks, bio., MDEA sep.	-276	-283	-287	-289	-289	2,391	2,366	2,354	2,347	2,347
14g	ULCORED gnf.wks, bio., MDEA sep.	-333	-341	-345	-347	-347	2,448	2,423	2,411	2,405	2,405
14b	ULCORED wks, bio., MDEA sep. (BAT)	-326	-333	-337	-339	-339	2,440	2,415	2,404	2,397	2,397
14.v	ULCORED wks, bio., VPSA sep.	-426	-434	-438	-440	-440	2,541	2,516	2,504	2,498	2,498
14g.v	ULCORED gnf.wks, bio., VPSA sep.	-434	-442	-445	-447	-447	2,549	2,524	2,512	2,506	2,506
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	-454	-462	-465	-467	-467	2,569	2,544	2,532	2,525	2,525
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	6.63	-140	-210	-248	-248	2,108	2,222	2,277	2,306	2,306
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	-8.22	-155	-225	-263	-263	2,123	2,237	2,292	2,321	2,321
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	-92.18	-215	-273	-305	-305	2,207	2,297	2,340	2,363	2,363
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	-101	-262	-339	-380	-380	2,216	2,344	2,405	2,438	2,438
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	-125	-285	-361	-402	-402	2,240	2,367	2,428	2,460	2,460
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	-194	-329	-394	-429	-429	2,309	2,412	2,461	2,487	2,487
15	ULCORED wks, exs bio.syng., MDEA sep.	-1,220	-1,228	-1,231	-1,233	-1,233	3,335	3,310	3,298	3,291	3,291
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	-1,243	-1,251	-1,255	-1,257	-1,257	3,358	3,333	3,321	3,315	3,315
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	-1,237	-1,245	-1,249	-1,251	-1,251	3,352	3,327	3,315	3,309	3,309
15.v	ULCORED wks, exs bio.syng., VPSA sep.	-1,275	-1,283	-1,287	-1,289	-1,289	3,390	3,365	3,353	3,347	3,347
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	-1,280	-1,288	-1,292	-1,294	-1,294	3,395	3,370	3,358	3,352	3,352
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	-1,290	-1,298	-1,301	-1,303	-1,303	3,405	3,380	3,368	3,362	3,362
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	-832	-1,014	-1,101	-1,148	-1,148	2,947	3,096	3,168	3,206	3,206
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	-846	-1,029	-1,116	-1,163	-1,163	2,961	3,111	3,182	3,221	3,221
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	-932	-1,090	-1,166	-1,206	-1,206	3,047	3,172	3,232	3,264	3,264
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	-1,020	-1,157	-1,223	-1,258	-1,258	3,135	3,239	3,289	3,316	3,316
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	-1,043	-1,170	-1,230	-1,263	-1,263	3,158	3,252	3,297	3,321	3,321
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	-1,120	-1,214	-1,259	-1,283	-1,283	3,235	3,296	3,326	3,341	3,341
16	ULCOWIN wks, imp.elec.	1,369	846	595	461	461	745	1,236	1,471	1,597	1,597
16g	ULCOWIN gnf.wks, imp.elec.	1,341	820	570	436	436	773	1,262	1,496	1,622	1,622
16b	ULCOWIN wks, imp.elec. (BAT)	1,266	770	532	404	404	849	1,313	1,535	1,654	1,654

Table A-24: Abatements of technology sites constructed for the UK iron and steel sector

ID	Description	SE_2 (2010; 2023 Grid EF: 38% decarb. from 2007)	SE_2 (2020; 2023 Grid EF: 66% decarb. from 2007)	SE_2 (2030; 2023 Grid EF: 78% decarb. from 2007)	SE_2 (2040; 2023 Grid EF: 85% decarb. from 2007)	SE_2 (2050; 2023 Grid EF: 85% decarb. from 2007)	Abatement (2010)	Abatement (2020)	Abatement (2030)	Abatement (2040)	Abatement (2050)
		$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	1,842	1,790	1,765	1,751	1,751	273	292	302	307	307
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	1,645	1,598	1,576	1,564	1,564	470	484	491	494	494
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	1,489	1,445	1,423	1,412	1,412	626	638	643	646	646
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	1,326	1,286	1,267	1,257	1,257	789	796	799	801	801
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	1,731	1,669	1,639	1,623	1,623	383	413	427	435	435
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	1,547	1,490	1,462	1,448	1,448	568	593	604	611	611
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	1,403	1,351	1,325	1,312	1,312	712	732	741	746	746
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	1,240	1,192	1,169	1,157	1,157	874	890	897	901	901
6.2	TGR-BF [V4] wks, MDEA sep.	1,089	1,037	1,012	999	999	1,026	1,045	1,054	1,059	1,059
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	893	846	823	811	811	1,222	1,236	1,243	1,247	1,247
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	905	861	840	828	828	1,210	1,221	1,227	1,230	1,230
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	743	703	683	673	673	1,372	1,380	1,383	1,385	1,385
6.2.v	TGR-BF [V4] wks, VPSA sep.	979	917	887	871	871	1,136	1,165	1,180	1,187	1,187
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	794	737	710	695	695	1,321	1,345	1,357	1,363	1,363
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	819	767	742	729	729	1,296	1,315	1,325	1,330	1,330
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	657	609	586	574	574	1,458	1,473	1,481	1,485	1,485
7	Hlsarna wks	186	183	181	180	180	1,928	1,900	1,886	1,878	1,878
7b	Hlsarna wks (BAT)	129	129	129	129	129	1,986	1,953	1,937	1,929	1,929
7s	Hlsarna wks, max scrap	196	181	173	169	169	1,919	1,902	1,893	1,889	1,889
7bs	Hlsarna wks, max scrap (BAT)	127	122	119	118	118	1,988	1,960	1,947	1,940	1,940
8	Hlsarna wks, MDEA sep.	-819	-902	-941	-962	-962	2,934	2,984	3,008	3,020	3,020
8b	Hlsarna wks, MDEA sep. (BAT)	-897	-969	-1,003	-1,021	-1,021	3,012	3,051	3,069	3,079	3,079
8s	Hlsarna wks, max scrap, MDEA sep.	-574	-654	-692	-713	-713	2,689	2,736	2,759	2,771	2,771
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	-647	-717	-750	-768	-768	2,762	2,799	2,817	2,826	2,826
8.v	Hlsarna wks, VPSA sep.	-838	-904	-936	-953	-953	2,953	2,987	3,003	3,011	3,011
8b.v	Hlsarna wks, VPSA sep. (BAT)	-916	-971	-998	-1,012	-1,012	3,031	3,054	3,064	3,070	3,070
8s.v	Hlsarna wks, max scrap, VPSA sep.	-588	-656	-688	-706	-706	2,703	2,738	2,755	2,764	2,764
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	-662	-719	-746	-761	-761	2,776	2,801	2,813	2,819	2,819
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	1,842	1,790	1,765	1,751	1,751	273	292	302	307	307
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	1,645	1,598	1,576	1,564	1,564	470	484	491	494	494
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	1,489	1,445	1,423	1,412	1,412	626	638	643	646	646
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	1,326	1,286	1,267	1,257	1,257	789	796	799	801	801
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	1,731	1,669	1,639	1,623	1,623	383	413	427	435	435
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	1,547	1,490	1,462	1,448	1,448	568	593	604	611	611
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	1,403	1,351	1,325	1,312	1,312	712	732	741	746	746
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	1,240	1,192	1,169	1,157	1,157	874	890	897	901	901
8	Hlsarna wks, MDEA sep.	354	272	233	212	212	1,760	1,810	1,834	1,847	1,847
8b	Hlsarna wks, MDEA sep. (BAT)	276	205	171	153	153	1,839	1,877	1,896	1,905	1,905
8s	Hlsarna wks, max scrap, MDEA sep.	337	257	218	198	198	1,778	1,826	1,848	1,860	1,860
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	263	194	160	142	142	1,851	1,888	1,906	1,916	1,916
8.v	Hlsarna wks, VPSA sep.	335	269	237	220	220	1,779	1,813	1,829	1,838	1,838
8b.v	Hlsarna wks, VPSA sep. (BAT)	257	202	176	162	162	1,857	1,880	1,891	1,897	1,897
8s.v	Hlsarna wks, max scrap, VPSA sep.	322	254	222	205	205	1,793	1,828	1,845	1,854	1,854
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	249	191	164	149	149	1,866	1,891	1,902	1,909	1,909
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	1,340	1,288	1,263	1,250	1,250	775	794	803	808	808
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	1,143	1,097	1,074	1,062	1,062	971	986	992	996	996
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	1,100	1,055	1,034	1,023	1,023	1,015	1,027	1,032	1,035	1,035
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	937	897	878	868	868	1,178	1,185	1,188	1,190	1,190
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	1,230	1,167	1,138	1,122	1,122	885	915	929	936	936
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	1,045	988	961	946	946	1,070	1,094	1,106	1,112	1,112
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	1,014	962	936	923	923	1,101	1,121	1,130	1,135	1,135
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	851	803	780	768	768	1,263	1,279	1,286	1,290	1,290
8	Hlsarna wks, MDEA sep.	-428	-510	-550	-571	-571	2,543	2,593	2,616	2,629	2,629
8b	Hlsarna wks, MDEA sep. (BAT)	-506	-577	-611	-630	-630	2,621	2,660	2,678	2,688	2,688
8s	Hlsarna wks, max scrap, MDEA sep.	-270	-350	-389	-409	-409	2,385	2,432	2,455	2,467	2,467
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	-343	-413	-447	-464	-464	2,458	2,495	2,513	2,523	2,523
8.v	Hlsarna wks, VPSA sep.	-447	-513	-545	-562	-562	2,562	2,595	2,612	2,620	2,620
8b.v	Hlsarna wks, VPSA sep. (BAT)	-525	-580	-607	-621	-621	2,640	2,662	2,673	2,679	2,679
8s.v	Hlsarna wks, max scrap, VPSA sep.	-285	-353	-385	-402	-402	2,400	2,435	2,451	2,460	2,460
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	-358	-415	-443	-458	-458	2,473	2,498	2,509	2,516	2,516

Table A-25: Abatements of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	Project	Variable OPEX	Fixed OPEX - plant and equip.	Fixed OPEX - other	Total OPEX	Plant CAPEX	Plant aux., spare parts and	Site dev. (Gnf. only)	Total CAPEX	Working capital (Included for Gnf.)	Recurring capital (15th year relining)	Production cost	Error (+/-)	Abatement cost	Abatement cost, 85% grid decarb.
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs		£/tcs	£/tcs	£/tcs	£/tcs		£/tCO$_2$e	£/tCO$_2$e
0	Sector (Base)	Existing site modification	235	30.87	62.69	329	254	57.17		311	43.76	38.87	365	28%		
0p	Sector (TP)	Existing site modification	223	30.78	62.69	316	314	10.21		324	39.27	38.87	354	29%	-63.60	-83.09
0p2	Sector (TP2)	Existing site modification	221	30.55	62.69	314	302	7.52		309	39.27	38.87	350	29%	-81.17	-110
0b	Sector (BAT)	Existing site modification	213	32.16	62.69	308	343	9.93		353	39.27	38.87	349	29%	-63.68	-104
1	Int.wks (Base)	Existing site modification	235	33.89	70.06	339	282	63.42		345	46.08	49.23	379	27%		
1p	Int.wks (TP)	Existing site modification	221	34.10	70.06	326	340	76.45		416	41.92	49.23	374	29%	-26.62	-33.46
1b	Int.wks (BAT)	Existing site modification	213	36.10	70.06	319	379	85.19		464	41.92	49.23	373	29%	-23.79	-37.41
1s	Int.wks max scrap	Existing site modification	231	30.92	70.06	331	257	57.75		314	41.74	38.18	368	28%	-27.00	-27.48
1bs	Int.wks max scrap (BAT)	Existing site modification	212	33.02	70.06	315	349	78.51		427	37.56	38.18	364	29%	-23.13	-27.22
2	EAF wks (Base)	Existing site modification	236	19.56	35.03	291	150	33.70		183	34.62		312	30%		
2p2	EAF wks (TP2)	Existing site modification	220	8.83	35.03	264	81.80	18.41		100	30.99		275	31%	-315	-870
2p	EAF wks (TP)	Existing site modification	229	18.30	35.03	282	216	48.52		264	30.99		312	32%	12.09	27.40
2b	EAF wks (BAT)	Existing site modification	215	17.37	35.03	268	210	47.20		257	30.99		297	31%	-98.29	-211
3g	EAF gnf.wks	Greenfield	275	17.93	46.24	339	293	66.02	112	472	35.49		401	31%	13.19	11.82
3gb	EAF gnf.wks (BAT)	Greenfield	259	19.36	46.24	325	322	72.43	112	506	34.38		391	32%	6.50	6.09
4	Int.wks, MEA sep.	Existing site modification	274	43.31	70.06	387	470	106		576	51.06	49.23	454	29%	75.05	69.52
4b	Int.wks, MEA sep. (BAT)	Existing site modification	244	43.92	70.06	358	539	121		660	46.84	49.23	434	30%	40.02	39.18
4s	Int.wks, max scrap, MEA sep.	Existing site modification	261	38.36	70.06	370	405	91.23		497	45.71	38.18	427	29%	39.87	38.13
4bs	Int.wks, max scrap, MEA sep. (BAT)	Existing site modification	237	38.95	70.06	346	472	106		578	41.56	38.18	412	30%	22.46	22.27
5	TGR-BF wks, MDEA sep. w/o storage	Existing site modification	244	38.11	70.06	352	409	91.92		500	43.95	48.28	410	28%	349	206
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	Existing site modification	226	41.07	70.06	337	497	112		609	41.17	48.28	408	29%	95.92	85.57
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	Existing site modification	237	34.15	70.06	341	354	79.76		434	40.11	37.44	392	28%	25.12	23.36
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	Existing site modification	223	36.92	70.06	330	440	99.11		540	37.67	37.44	392	29%	18.83	18.44
5.v	TGR-BF wks, VPSA sep. w/o storage	Existing site modification	236	35.76	70.06	342	362	81.34		443	42.95	48.28	393	28%	74.84	49.65
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	Existing site modification	220	38.71	70.06	328	450	101		551	40.20	48.28	392	28%	33.88	28.71
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	Existing site modification	231	32.32	70.06	333	318	71.54		390	39.33	37.44	378	28%	-1.77	-1.60
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	Existing site modification	216	35.09	70.06	321	404	90.90		495	36.80	37.44	379	28%	-1.09	-1.04
6	TGR-BF wks, MDEA sep.	Existing site modification	244	38.11	70.06	352	409	91.92		500	43.95	48.28	410	28%	36.45	33.98
6b	TGR-BF wks, MDEA sep. (BAT)	Existing site modification	226	41.07	70.06	337	497	112		609	41.17	48.28	408	29%	27.06	26.17
6s	TGR-BF wks, max scrap, MDEA sep.	Existing site modification	237	34.15	70.06	341	354	79.76		434	40.11	37.44	392	28%	11.41	11.04
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	Existing site modification	223	36.92	70.06	330	440	99.11		540	37.67	37.44	392	29%	9.98	9.86
6.v	TGR-BF wks, VPSA sep.	Existing site modification	236	35.76	70.06	342	362	81.34		443	42.95	48.28	393	28%	14.69	13.36
6b.v	TGR-BF wks, VPSA sep. (BAT)	Existing site modification	220	38.71	70.06	328	450	101		551	40.20	48.28	392	28%	11.31	10.67
6s.v	TGR-BF wks, max scrap, VPSA sep.	Existing site modification	231	32.32	70.06	333	318	71.54		390	39.33	37.44	378	28%	-0.87	-0.82
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	Existing site modification	216	35.09	70.06	321	404	90.90		495	36.80	37.44	379	28%	-0.61	-0.59
7	Hlsarna wks	Existing site modification	167	32.82	52.54	252	414	93.09		507	34.58	71.96	311	31%	-117	-138
7b	Hlsarna wks (BAT)	Existing site modification	158	33.62	52.54	244	475	107		582	33.31	71.96	312	32%	-105	-125
7s	Hlsarna wks, max scrap	Existing site modification	177	29.39	52.54	259	350	78.69		428	32.52	55.81	309	31%	-80.67	-86.12
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	169	30.15	52.54	252	410	92.31		503	31.15	55.81	310	32%	-72.68	-80.01
8	Hlsarna wks, MDEA sep.	Existing site modification	197	39.57	52.54	289	555	125		680	37.96	71.96	368	31%	-8.02	-7.28
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	188	40.37	52.54	280	616	139		755	36.92	71.96	368	32%	-7.48	-6.97
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	202	34.74	52.54	290	461	104		565	35.42	55.81	355	31%	-15.93	-14.57
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	194	35.50	52.54	282	521	117		639	33.87	55.81	356	32%	-14.73	-13.79
8.v	Hlsarna wks, VPSA sep.	Existing site modification	192	38.42	52.54	283	522	117		639	37.37	71.96	357	32%	-15.25	-14.30
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	182	39.21	52.54	274	583	131		714	35.74	71.96	357	32%	-14.33	-13.77
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	198	33.84	52.54	285	435	97.86		533	34.95	55.81	347	31%	-21.18	-19.85
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	190	34.60	52.54	277	495	111		607	33.43	55.81	347	32%	-19.72	-18.89
9	MIDREX wks	Existing site modification	216	36.86	46.24	299	456	103		559	33.02		362	33%	-13.43	-14.29
9g	MIDREX gnf.wks	Greenfield	213	34.81	46.24	294	653	147	112	912	32.86		410	33%	23.30	24.78
9b	MIDREX wks (BAT)	Existing site modification	203	35.22	46.24	284	507	114		621	30.61		355	34%	-17.83	-18.89
9.i	MIDREX wks, imp.elec.	Existing site modification	234	32.33	46.24	313	400	89.93		490	34.47		368	32%	-9.48	-7.91
9g.i	MIDREX gnf.wks, imp.elec.	Greenfield	233	32.32	46.24	312	552	124	112	788	34.98		413	32%	28.25	23.56
9b.i	MIDREX wks, imp.elec. (BAT)	Existing site modification	217	31.73	46.24	295	463	104		567	31.74		359	33%	-15.38	-13.67
10	MIDREX wks MDEA sep.	Existing site modification	226	41.72	46.24	314	549	124		672	34.45		390	33%	6.34	6.64
10g	MIDREX gnf.wks MDEA sep.	Greenfield	224	39.65	46.24	309	762	171	112	1,045	34.29		442	34%	35.70	37.36
10b	MIDREX wks MDEA sep. (BAT)	Existing site modification	212	39.64	46.24	298	591	133		724	31.87		380	34%	0.61	0.64
10.v	MIDREX wks VPSA sep.	Existing site modification	220	40.48	46.24	307	521	117		639	33.72		379	33%	0.07	0.07
10g.v	MIDREX gnf.wks VPSA sep.	Greenfield	218	38.42	46.24	302	730	164	112	1,007	33.57		430	34%	27.70	28.93
10b.v	MIDREX wks VPSA sep. (BAT)	Existing site modification	207	38.51	46.24	292	566	127		693	31.22		371	34%	-4.73	-4.94
11	ULCORED wks, NG, MDEA sep.	Existing site modification	218	42.51	46.24	307	562	126		688	34.22		385	35%	3.35	3.50
11g	ULCORED gnf.wks, NG, MDEA sep.	Greenfield	216	40.44	46.24	303	792	178	112	1,082	34.13		440	35%	33.61	35.14
11b	ULCORED wks, NG, MDEA sep. (BAT)	Existing site modification	205	40.40	46.24	291	603	136		739	31.79		375	36%	-2.26	-2.36
11.v	ULCORED wks, NG, VPSA sep.	Existing site modification	213	41.33	46.24	301	536	121		656	33.53		375	35%	-2.34	-2.45
11g.v	ULCORED gnf.wks, NG, VPSA sep.	Greenfield	210	39.27	46.24	296	762	171	112	1,045	33.43		428	35%	26.17	27.31
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	Existing site modification	200	39.35	46.24	285	580	130		710	31.19		366	36%	-7.05	-7.36
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	Existing site modification	241	35.14	46.24	322	456	103		558	36.00		386	34%	4.79	3.92
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	Greenfield	239	33.12	46.24	318	618	139	112	869	35.77		429	34%	35.74	29.41
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	Existing site modification	223	34.50	46.24	304	519	117		635	33.23		376	35%	-2.45	-2.13
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	Existing site modification	237	34.14	46.24	318	436	98.09		534	35.42		378	34%	-0.88	-0.72
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	Greenfield	234	32.12	46.24	313	590	133	112	835	35.18		419	34%	27.91	22.78
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	Existing site modification	219	33.54	46.24	299	499	112		612	32.73		368	34%	-7.06	-6.08
12	ULCORED wks, coal, MDEA sep.	Existing site modification	223	48.43	46.24	318	673	151		824	37.82		411	34%	19.70	20.70
12g	ULCORED gnf.wks, coal, MDEA sep.	Greenfield	221	46.70	46.24	314	943	212	112	1,267	37.62		475	34%	57.25	60.07
12b	ULCORED wks, coal, MDEA sep. (BAT)	Existing site modification	209	46.33	46.24	302	715	161		875	35.20		401	35%	13.06	13.70
12.v	ULCORED wks, coal, VPSA sep.	Existing site modification	212	45.99	46.24	304	618	139		758	36.39		390	34%	5.84	6.11
12g.v	ULCORED gnf.wks, coal, VPSA sep.	Greenfield	209	44.10	46.24	299	891	200	112	1,203	36.10		451	34%	40.23	42.06
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	Existing site modification	198	44.01	46.24	289	663	149		812	33.87		381	34%	0.74	0.77
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	Existing site modification	250	39.72	46.24	336	548	123		671	39.92		412	34%	28.92	21.75
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	Greenfield	248	37.75	46.24	332	731	165	112	1,008	39.56		461	33%	71.47	53.94
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	Existing site modification	231	39.10	46.24	317	611	137		748	36.96		402	33%	17.75	14.38
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	Existing site modification	241	37.10	46.24	325	495	111		607	38.72		393	32%	11.58	8.62
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	Greenfield	239	35.96	46.24	321	695	156	112	964	38.30		444	32%	51.52	38.60
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	Existing site modification	224	36.51	46.24	306	559	126		684	35.86		384	33%	3.38	2.70
13	ULCORED wks, exs coal syng., MDEA sep.	Existing site modification	248	59.19	46.24	353	874	197		1,071	44.67		474	34%	60.11	63.23
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	Greenfield	247	54.84	46.24	348	1,127	254	112	1,493	44.35		536	34%	95.98	101
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	Existing site modification	234	57.09	46.24	337	916	206		1,122	41.90		464	34%	52.01	54.62
13.v	ULCORED wks, exs coal syng., VPSA sep.	Existing site modification	233	53.98	46.24	334	760	171		931	42.76		439	34%	34.65	36.29
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	Greenfield	231	49.58	46.24	326	1,022	230	112	1,364	42.33		498	34%	69.10	72.36
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	Existing site modification	218	51.68	46.24	316	799	180		979	39.93		427	34%	27.44	28.73
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	Existing site modification	282	48.06	46.24	376	714	161		875	47.35		475	32%	100	66.21
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	Greenfield	281	45.27	46.24	372	903	203	112	1,218	46.95		527	32%	152	101
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	Existing site modification	263	47.42	46.24	357	777	175		952	44.25		465	33%	78.68	56.84
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	Existing site modification	252	45.58	46.24	344	642	144		786	44.20		433	32%	43.18	33.25
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	Greenfield	248	44.78	46.24	339	910	205	112	1,227	43.73		495	32%	90.49	71.35
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	Existing site modification	232	45.49	46.24	324	711	160		871	40.72		423	33%	31.23	26.41
14	ULCORED wks, bio., MDEA sep.	Existing site modification	321	46.99	46.24	415	645	145		791	56.09		504	44%	51.55	53.26
14g	ULCORED gnf.wks, bio., MDEA sep.	Greenfield	320	45.61	46.24	412	921	207	112	1,240	55.85		571	43%	77.05	79.55
14b	ULCORED wks, bio., MDEA sep. (BAT)	Existing site modification	308	44.89	46.24	399	687	155		842	53.38		494	45%	46.45	47.96
14.v	ULCORED wks, bio., VPSA sep.	Existing site modification	311	44.91	46.24	402	599	135		734	54.73		485	44%	40.98	42.26
14g.v	ULCORED gnf.wks, bio., VPSA sep.	Greenfield	309	43.31	46.24	399	875	197	112	1,184	54.53		550	43%	66.23	68.30
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	Existing site modification	299	42.93	46.24	388	643	145		788	52.27		477	45%	37.58	38.74
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	Existing site modification	347	38.54	46.24	432	524	118		642	58.13		505	43%	64.48	54.51
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	Greenfield	346	36.67	46.24	429	710	160	112	981	57.73		556	42%	89.96	76.11
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	Existing site modification	329	37.90	46.24	413	587	132		719	55.08		495	44%	55.49	48.89
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	Existing site modification	340	36.39	46.24	423	481	108		589	57.12		490	43%	54.24	45.34
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	Greenfield	338	35.24	46.24	419	681	153	112	946	56.62		542	42%	78.74	66.01
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	Existing site modification	323	35.79	46.24	405	544	122		667	54.16		480	44%	46.62	40.57
15	ULCORED wks, exs bio.syng., MDEA sep.	Existing site modification	455	56.09	46.24	558	815	183		999	83.44		671	50%	86.54	88.60
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	Greenfield	457	52.45	46.24	556	1,079	243	112	1,434	83.35		741	49%	107	109
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	Existing site modification	444	53.59	46.24	545	857	133		1,050	80.83		664	51%	83.98	85.96
15.v	ULCORED wks, exs bio.syng., VPSA sep.	Existing site modification	448	51.61	46.24	545	718	162		879	82.30		645	51%	77.60	79.41
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	Greenfield	441	47.71	46.24	535	984	221	112	1,318	81.37		706	49%	95.27	97.48
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	Existing site modification	431	49.22	46.24	526	755	170		925	79.13		631	51%	73.25	74.95
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	Existing site modification	491	45.49	46.24	583	663	149		812	86.33		675	49%	108	92.15
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	Greenfield	490	42.97	46.24	579	857	193	112	1,162	85.82		731	48%	128	109
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	Existing site modification	473	44.85	46.24	564	726	163		889	83.06		664	50%	99.27	87.36
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	Existing site modification	464	44.06	46.24	555	611	137		748	83.59		640	50%	87.05	78.47
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	Greenfield	460	43.25	46.24	549	880	198	112	1,190	82.94		704	49%	107	97.91
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	Existing site modification	442	44.17	46.24	533	683	154		837	80.03		628	51%	78.83	74.30
16	ULCOWIN wks, imp.elec.	Existing site modification	386	37.27	46.24	469	498	112		611	51.97		538	35%	2.595	99.53
16g	ULCOWIN gnf.wks, imp.elec.	Greenfield	382	35.26	46.24	464	640	144	112	896	51.43		579	35%	2.182	123
16b	ULCOWIN wks, imp.elec. (BAT)	Existing site modification	366	36.68	46.24	449	562	126		689	48.85		527	35%	731	89.47

Table A-26: Static economics of technology sites constructed for the UK iron and steel sector

ID	Description	Project	Variable OPEX	Fixed OPEX - plant and equip.	Fixed OPEX - other	Total OPEX	Plant CAPEX	Plant aux., spare parts and	Site dev. (Gnf. only)	Total CAPEX	Working capital (Included for Gnf.)	Recurring capital (15th year relining)	Production cost	Error (+/-)	Abatement cost	Abatement cost, 85% grid decarb.
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs		£/tcs	£/tcs	£/tcs	£/tcs		£/tCO2e	£/tCO2e
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	Existing site modification	237	37.31	70.06	345	406	91.31		497	43.95	48.28	402	28%	93.33	74.90
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	Existing site modification	220	40.10	70.06	331	491	110		601	41.17	48.28	400	29%	45.98	41.85
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	Existing site modification	232	33.53	70.06	336	352	79.28		432	40.11	37.44	385	28%	10.14	9.57
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	Existing site modification	218	36.15	70.06	324	435	97.98		533	37.67	37.44	386	29%	8.06	7.83
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	Existing site modification	229	34.96	70.06	334	359	80.74		440	42.95	48.28	385	28%	17.84	14.03
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	Existing site modification	213	37.75	70.06	321	444	99.89		544	40.20	48.28	384	28%	9.14	8.00
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	Existing site modification	226	31.70	70.06	327	316	71.07		387	39.33	37.44	372	28%	-10.25	-9.41
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	Existing site modification	212	34.33	70.06	316	399	89.77		489	36.80	37.44	372	28%	-8.09	-7.66
6.2	TGR-BF [V4] wks, MDEA sep.	Existing site modification	237	37.31	70.06	345	406	91.31		497	43.95	48.28	402	28%	23.01	21.69
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	Existing site modification	220	40.10	70.06	331	491	110		601	41.17	48.28	400	29%	17.21	16.60
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	Existing site modification	232	33.53	70.06	336	352	79.28		432	40.11	37.44	385	28%	5.18	5.03
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	Existing site modification	218	36.15	70.06	324	435	97.98		533	37.67	37.44	386	29%	4.61	4.53
6.2.v	TGR-BF [V4] wks, VPSA sep.	Existing site modification	229	34.96	70.06	334	359	80.74		440	42.95	48.28	385	28%	5.58	5.14
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	Existing site modification	213	37.75	70.06	321	444	99.89		544	40.20	48.28	384	28%	3.80	3.58
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	Existing site modification	226	31.70	70.06	327	316	71.07		387	39.33	37.44	372	28%	-5.54	-5.28
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	Existing site modification	212	34.33	70.06	316	399	89.77		489	36.80	37.44	372	28%	-4.80	-4.65
7	Hlsarna wks	Existing site modification	416	32.82	52.54	501	414	93.09		507	34.58	71.96	560	53%	140	96.44
7b	Hlsarna wks (BAT)	Existing site modification	407	33.62	52.54	493	475	107		582	33.31	71.96	561	54%	134	94.09
7s	Hlsarna wks, max scrap	Existing site modification	371	29.39	52.54	452	350	78.69		428	32.52	55.81	502	50%	86.77	65.22
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	362	30.15	52.54	445	410	92.31		503	31.15	55.81	503	50%	82.53	63.95
8	Hlsarna wks, MDEA sep.	Existing site modification	447	39.91	52.54	540	563	127		689	37.96	71.96	620	51%	110	79.57
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	438	40.71	52.54	531	624	140		764	36.92	71.96	620	52%	105	78.07
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	397	35.00	52.54	484	467	105		572	35.42	55.81	551	49%	81.60	61.81
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	388	35.76	52.54	476	527	119		646	33.87	55.81	551	49%	78.58	60.78
8.v	Hlsarna wks, VPSA sep.	Existing site modification	442	38.69	52.54	533	527	119		646	37.37	71.96	608	52%	103	75.98
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	432	39.49	52.54	525	588	132		721	35.74	71.96	608	52%	98.45	74.53
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	392	34.06	52.54	479	439	98.82		538	34.95	55.81	542	49%	76.13	58.69
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	384	34.82	52.54	471	500	112		612	33.43	55.81	542	49%	73.36	57.72
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	Existing site modification	200	37.31	70.06	307	406	91.31		497	43.95	48.28	365	26%	-59.50	-47.75
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	Existing site modification	183	40.10	70.06	293	491	110		601	41.17	48.28	362	26%	-37.61	-34.24
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	Existing site modification	203	33.53	70.06	306	352	79.28		432	40.11	37.44	356	27%	-37.71	-35.59
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	Existing site modification	189	36.15	70.06	295	435	97.98		533	37.67	37.44	356	27%	-29.42	-28.58
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	Existing site modification	192	34.96	70.06	297	359	80.74		440	42.95	48.28	348	25%	-92.11	-72.46
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	Existing site modification	176	37.75	70.06	284	444	99.89		544	40.20	48.28	347	26%	-61.30	-53.61
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	Existing site modification	196	31.70	70.06	298	316	71.07		387	39.33	37.44	343	26%	-52.86	-48.52
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	Existing site modification	182	34.33	70.06	287	399	89.77		489	36.80	37.44	343	27%	-42.29	-40.04
8	Hlsarna wks, MDEA sep.	Existing site modification	388	39.91	52.54	481	563	127		689	37.96	71.96	561	51%	179	98.36
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	379	40.71	52.54	473	624	140		764	36.92	71.96	561	52%	164	95.36
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	351	35.00	52.54	439	467	105		572	35.42	55.81	505	48%	106	67.58
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	343	35.76	52.54	431	527	119		646	33.87	55.81	506	49%	98.97	65.91
8.v	Hlsarna wks, VPSA sep.	Existing site modification	383	38.69	52.54	474	527	119		646	37.37	71.96	549	52%	161	92.57
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	374	39.49	52.54	466	588	132		721	35.74	71.96	549	52%	148	89.71
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	347	34.06	52.54	434	439	98.82		538	34.95	55.81	496	49%	95.63	62.96
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	338	34.82	52.54	426	500	112		612	33.43	55.81	497	49%	89.63	61.41
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	Existing site modification	200	37.31	70.06	307	406	91.31		497	43.95	48.28	365	26%	-19.59	-18.12
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	Existing site modification	183	40.10	70.06	293	491	110		601	41.17	48.28	362	26%	-17.79	-17.00
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	Existing site modification	203	33.53	70.06	306	352	79.28		432	40.11	37.44	356	27%	-23.02	-22.21
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	Existing site modification	189	36.15	70.06	295	435	97.98		533	37.67	37.44	356	27%	-19.62	-19.24
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	Existing site modification	192	34.96	70.06	297	359	80.74		440	42.95	48.28	348	25%	-37.35	-33.65
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	Existing site modification	176	37.75	70.06	284	444	99.89		544	40.20	48.28	347	26%	-31.61	-29.43
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	Existing site modification	196	31.70	70.06	298	316	71.07		387	39.33	37.44	343	26%	-33.71	-31.89
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	Existing site modification	182	34.33	70.06	287	399	89.77		489	36.80	37.44	343	27%	-29.05	-27.97
8	Hlsarna wks, MDEA sep.	Existing site modification	388	39.91	52.54	481	563	127		689	37.96	71.96	561	51%	101	69.09
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	379	40.71	52.54	473	624	140		764	36.92	71.96	561	52%	96.06	67.60
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	351	35.00	52.54	439	467	105		572	35.42	55.81	505	48%	70.04	50.96
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	343	35.76	52.54	431	527	119		646	33.87	55.81	506	49%	67.07	50.05
8.v	Hlsarna wks, VPSA sep.	Existing site modification	383	38.69	52.54	474	527	119		646	37.37	71.96	549	52%	92.49	64.92
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	374	39.49	52.54	466	588	132		721	35.74	71.96	549	52%	88.02	63.50
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	347	34.06	52.54	434	439	98.82		538	34.95	55.81	496	49%	63.87	47.43
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	338	34.82	52.54	426	500	112		612	33.43	55.81	497	49%	61.22	46.59

Table A-27: Static economics of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	Project	Plant CAPEX	Total CAPEX	Production cost	Error (+/-)	Abatement cost	Abatement cost, 85% grid decarbonisation
			£/tcs	£/tcs	£/tcs		£/tCO$_2$e	£/tCO$_2$e
0	Sector (Base)	Brownfield; New assets	571	699	416	27%		
0p	Sector (TP)	Brownfield; New assets	578	589	384	30%	-187	-245
0p2	Sector (TP2)	Brownfield; New assets	590	603	384	30%	-180	-244
0b	Sector (BAT)	Brownfield; New assets	613	623	386	30%	-120	-195
1	Int.wks (Base)	Brownfield; New assets	643	787	437	27%		
1p	Int.wks (TP)	Brownfield; New assets	671	822	428	30%	-45.84	-57.62
1b	Int.wks (BAT)	Brownfield; New assets	718	880	429	29%	-31.07	-48.86
1s	Int.wks max scrap	Brownfield; New assets	575	704	419	27%	-43.52	-44.28
1bs	Int.wks max scrap (BAT)	Brownfield; New assets	651	797	414	30%	-35.62	-41.93
2	EAF wks (Base)	Brownfield; New assets	300	367	336	30%		
2p2	EAF wks (TP2)	Brownfield; New assets	131	161	282	31%	-468	-1,292
2p	EAF wks (TP)	Brownfield; New assets	228	280	314	31%	-319	-724
2b	EAF wks (BAT)	Brownfield; New assets	217	265	300	31%	-238	-510
3g	EAF gnf.wks	Greenfield	293	472	401	31%	-21.84	-19.56
3gb	EAF gnf.wks (BAT)	Greenfield	322	506	391	32%	-26.49	-24.78
4	Int.wks, MEA sep.	Brownfield; New assets	861	1,055	519	28%	81.97	75.93
4b	Int.wks, MEA sep. (BAT)	Brownfield; New assets	887	1,087	493	30%	40.88	40.02
4s	Int.wks, max scrap, MEA sep.	Brownfield; New assets	748	916	484	28%	38.73	37.04
4bs	Int.wks, max scrap, MEA sep. (BAT)	Brownfield; New assets	776	951	464	30%	18.19	18.04
5	TGR-BF wks, MDEA sep. w/o storage	Brownfield; New assets	685	839	457	28%	221	130
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	Brownfield; New assets	769	942	455	29%	59.53	53.11
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	Brownfield; New assets	606	743	434	28%	-7.00	-6.51
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	Brownfield; New assets	690	845	435	29%	-3.90	-3.82
5.v	TGR-BF wks, VPSA sep. w/o storage	Brownfield; New assets	625	766	437	27%	0.14	0.09
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	Brownfield; New assets	710	869	437	29%	-1.25	-1.06
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	Brownfield; New assets	560	686	419	28%	-33.06	-29.79
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	Brownfield; New assets	644	788	420	29%	-24.15	-22.93
6	TGR-BF wks, MDEA sep.	Brownfield; New assets	685	839	457	28%	23.07	21.51
6b	TGR-BF wks, MDEA sep. (BAT)	Brownfield; New assets	769	942	455	29%	16.79	16.24
6s	TGR-BF wks, max scrap, MDEA sep.	Brownfield; New assets	606	743	434	28%	-3.18	-3.08
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	690	845	435	29%	-2.07	-2.04
6.v	TGR-BF wks, VPSA sep.	Brownfield; New assets	625	766	437	27%	0.03	0.02
6b.v	TGR-BF wks, VPSA sep. (BAT)	Brownfield; New assets	710	869	437	29%	-0.42	-0.39
6s.v	TGR-BF wks, max scrap, VPSA sep.	Brownfield; New assets	560	686	419	28%	-16.20	-15.38
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	644	788	420	29%	-13.44	-13.05
7	Hlsarna wks	Brownfield; New assets	613	751	347	31%	-156	-184
7b	Hlsarna wks (BAT)	Brownfield; New assets	660	808	346	32%	-142	-169
7s	Hlsarna wks, max scrap	Brownfield; New assets	533	653	341	31%	-111	-118
7bs	Hlsarna wks, max scrap (BAT)	Brownfield; New assets	579	709	341	32%	-101	-112
8	Hlsarna wks, MDEA sep.	Brownfield; New assets	744	911	403	31%	-23.88	-21.67
8b	Hlsarna wks, MDEA sep. (BAT)	Brownfield; New assets	790	968	402	32%	-23.29	-21.71
8s	Hlsarna wks, max scrap, MDEA sep.	Brownfield; New assets	637	781	388	31%	-32.94	-30.14
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	683	837	387	32%	-31.73	-29.72
8.v	Hlsarna wks, VPSA sep.	Brownfield; New assets	728	891	395	31%	-29.18	-27.36
8b.v	Hlsarna wks, VPSA sep. (BAT)	Brownfield; New assets	774	949	393	32%	-28.32	-27.22
8s.v	Hlsarna wks, max scrap, VPSA sep.	Brownfield; New assets	625	765	381	31%	-36.75	-34.43
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	671	822	380	32%	-35.36	-33.87
9	MIDREX wks	Brownfield; New assets	665	815	399	33%	-29.67	-31.58
9g	MIDREX gnf.wks	Greenfield	653	912	410	33%	-20.92	-22.24
9b	MIDREX wks (BAT)	Brownfield; New assets	571	700	371	34%	-48.34	-51.23
9.i	MIDREX wks, imp.elec.	Brownfield; New assets	552	676	396	31%	-35.28	-29.43
9g.i	MIDREX gnf.wks, imp.elec.	Greenfield	552	788	413	32%	-21.14	-17.64
9b.i	MIDREX wks, imp.elec. (BAT)	Brownfield; New assets	484	593	368	32%	-53.59	-47.62
10	MIDREX wks MDEA sep.	Brownfield; New assets	774	948	431	33%	-3.69	-3.86
10g	MIDREX gnf.wks MDEA sep.	Greenfield	762	1,045	442	34%	2.54	2.66
10b	MIDREX wks MDEA sep. (BAT)	Brownfield; New assets	670	821	400	34%	-21.22	-22.19
10.v	MIDREX wks VPSA sep.	Brownfield; New assets	743	910	419	33%	-10.03	-10.48
10g.v	MIDREX gnf.wks VPSA sep.	Greenfield	730	1,007	430	34%	-4.01	-4.19
10b.v	MIDREX wks VPSA sep. (BAT)	Brownfield; New assets	642	786	389	34%	-26.15	-27.30
11	ULCORED wks, NG, MDEA sep.	Brownfield; New assets	804	985	429	35%	-4.93	-5.15
11g	ULCORED gnf.wks, NG, MDEA sep.	Greenfield	792	1,082	440	35%	1.26	1.31
11b	ULCORED wks, NG, MDEA sep. (BAT)	Brownfield; New assets	699	857	397	36%	-22.14	-23.12
11.v	ULCORED wks, NG, VPSA sep.	Brownfield; New assets	774	948	418	35%	-10.74	-11.21
11g.v	ULCORED gnf.wks, NG, VPSA sep.	Greenfield	762	1,045	428	35%	-4.86	-5.07
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	Brownfield; New assets	672	824	387	36%	-26.62	-27.76
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	Brownfield; New assets	629	770	418	33%	-14.63	-11.98
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	Greenfield	618	869	429	34%	-6.25	-5.14
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	Brownfield; New assets	559	685	388	34%	-33.05	-28.71
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	Brownfield; New assets	601	736	408	33%	-20.66	-16.78
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	Greenfield	590	835	419	34%	-12.62	-10.30
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	Brownfield; New assets	533	653	380	34%	-37.64	-32.42
12	ULCORED wks, coal, MDEA sep.	Brownfield; New assets	948	1,161	461	34%	14.51	15.25
12g	ULCORED gnf.wks, coal, MDEA sep.	Greenfield	943	1,267	475	34%	22.31	23.41
12b	ULCORED wks, coal, MDEA sep. (BAT)	Brownfield; New assets	843	1,033	429	35%	-4.98	-5.22
12.v	ULCORED wks, coal, VPSA sep.	Brownfield; New assets	886	1,085	438	34%	0.10	0.10
12g.v	ULCORED gnf.wks, coal, VPSA sep.	Greenfield	891	1,203	451	34%	7.81	8.17
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	Brownfield; New assets	784	960	407	34%	-16.73	-17.48
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	Brownfield; New assets	741	908	448	32%	9.11	6.85
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	Greenfield	731	1,008	461	33%	20.35	15.36
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	Brownfield; New assets	671	822	418	33%	-15.32	-12.41
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	Brownfield; New assets	671	823	426	32%	-9.17	-6.83
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	Greenfield	695	964	444	32%	5.01	3.75
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	Brownfield; New assets	603	739	397	33%	-29.55	-23.57
13	ULCORED wks, exs coal syng., MDEA sep.	Brownfield; New assets	1,209	1,481	536	33%	62.11	65.34
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	Greenfield	1,127	1,493	536	34%	60.43	63.46
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	Brownfield; New assets	1,105	1,353	504	34%	40.75	42.79
13.v	ULCORED wks, exs coal syng., VPSA sep.	Brownfield; New assets	1,079	1,321	497	33%	34.26	35.88
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	Greenfield	1,022	1,364	499	34%	35.52	37.19
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	Brownfield; New assets	970	1,189	463	34%	14.58	15.27
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	Brownfield; New assets	945	1,157	519	31%	85.22	56.18
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	Greenfield	903	1,218	527	32%	92.56	61.33
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	Brownfield; New assets	875	1,072	489	32%	47.68	34.44
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	Brownfield; New assets	878	1,075	477	31%	31.51	24.27
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	Greenfield	910	1,227	495	32%	45.02	35.50
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	Brownfield; New assets	822	1,007	448	33%	7.71	6.52
14	ULCORED wks, bio., MDEA sep.	Brownfield; New assets	915	1,121	553	43%	47.66	49.24
14g	ULCORED gnf.wks, bio., MDEA sep.	Greenfield	921	1,240	571	43%	53.64	55.38
14b	ULCORED wks, bio., MDEA sep. (BAT)	Brownfield; New assets	811	993	521	44%	33.92	35.02
14.v	ULCORED wks, bio., VPSA sep.	Brownfield; New assets	862	1,057	532	43%	36.72	37.87
14g.v	ULCORED gnf.wks, bio., VPSA sep.	Greenfield	875	1,184	550	43%	43.74	45.10
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	Brownfield; New assets	761	932	503	45%	25.11	25.89
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	Brownfield; New assets	715	875	540	42%	52.73	44.58
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	Greenfield	710	981	556	42%	60.37	51.07
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	Brownfield; New assets	645	790	511	43%	35.25	31.06
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	Brownfield; New assets	657	805	522	42%	41.69	34.84
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	Greenfield	681	946	542	42%	50.56	42.39
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	Brownfield; New assets	589	722	494	43%	25.97	22.60
15	ULCORED wks, exs bio.syng., MDEA sep.	Brownfield; New assets	1,140	1,396	730	48%	86.81	88.86
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	Greenfield	1,079	1,434	741	49%	89.56	91.67
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	Brownfield; New assets	1,035	1,268	701	50%	77.86	79.70
15.v	ULCORED wks, exs bio.syng., VPSA sep.	Brownfield; New assets	1,028	1,259	701	49%	76.88	78.68
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	Greenfield	984	1,318	706	49%	78.32	80.14
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	Brownfield; New assets	918	1,124	665	50%	66.20	67.74
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	Brownfield; New assets	888	1,088	717	47%	102	87.16
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	Greenfield	857	1,162	731	48%	107	91.21
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	Brownfield; New assets	818	1,002	687	49%	87.00	76.56
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	Brownfield; New assets	847	1,038	683	48%	82.07	73.98
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	Greenfield	880	1,190	704	49%	88.22	80.41
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	Brownfield; New assets	797	976	653	50%	68.50	64.55
16	ULCOWIN wks, imp.elec.	Brownfield; New assets	651	797	567	35%	2,121	81.35
16g	ULCOWIN gnf.wks, imp.elec.	Greenfield	640	896	579	35%	1,549	87.58
16b	ULCOWIN wks, imp.elec. (BAT)	Brownfield; New assets	583	714	537	36%	493	60.38

Table A-28: Static economics of alternative site projects for the UK iron and steel sector

ID	Description	Project	Plant CAPEX	Total CAPEX	Production cost	+/- % Error	Abatement cost	Abatement cost, 85% grid decarbonisation
			£/tcs	£/tcs	£/tcs	£/tCO_2e	£/tCO_2e	£/tcs
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	Brownfield; New assets	669	819	447	28%	39.19	31.45
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	Brownfield; New assets	749	917	445	29%	17.01	15.49
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	Brownfield; New assets	594	727	426	28%	-18.12	-17.10
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	Brownfield; New assets	673	825	427	29%	-13.48	-13.10
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	Brownfield; New assets	609	746	428	27%	-28.39	-22.33
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	Brownfield; New assets	689	844	427	28%	-19.93	-17.43
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	Brownfield; New assets	547	671	411	28%	-38.25	-35.11
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	Brownfield; New assets	627	768	412	29%	-30.01	-28.42
6.2	TGR-BF [V4] wks, MDEA sep.	Brownfield; New assets	669	819	447	28%	9.66	9.11
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	Brownfield; New assets	749	917	445	29%	6.37	6.14
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	Brownfield; New assets	594	727	426	28%	-9.26	-8.99
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	673	825	427	29%	-7.71	-7.58
6.2.v	TGR-BF [V4] wks, VPSA sep.	Brownfield; New assets	609	746	428	27%	-8.87	-8.18
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	Brownfield; New assets	689	844	427	28%	-8.27	-7.81
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	Brownfield; New assets	547	671	411	28%	-20.65	-19.70
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	627	768	412	29%	-17.82	-17.25
7	Hlsarna wks	Brownfield; New assets	613	751	596	52%	123	84.32
7b	Hlsarna wks (BAT)	Brownfield; New assets	660	808	595	52%	116	81.57
7s	Hlsarna wks, max scrap	Brownfield; New assets	533	653	535	49%	68.47	51.47
7bs	Hlsarna wks, max scrap (BAT)	Brownfield; New assets	579	709	534	49%	64.27	49.80
8	Hlsarna wks, MDEA sep.	Brownfield; New assets	750	919	655	50%	99.40	72.04
8b	Hlsarna wks, MDEA sep. (BAT)	Brownfield; New assets	797	976	654	50%	94.74	70.24
8s	Hlsarna wks, max scrap, MDEA sep.	Brownfield; New assets	642	787	583	47%	69.35	52.52
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	688	843	582	48%	66.13	51.16
8.v	Hlsarna wks, VPSA sep.	Brownfield; New assets	733	898	646	50%	93.43	69.20
8b.v	Hlsarna wks, VPSA sep. (BAT)	Brownfield; New assets	780	955	644	51%	89.08	67.43
8s.v	Hlsarna wks, max scrap, VPSA sep.	Brownfield; New assets	629	771	576	48%	64.91	50.04
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	675	827	575	48%	61.92	48.72
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	Brownfield; New assets	669	819	409	26%	-114	-91.20
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	Brownfield; New assets	749	917	407	27%	-66.57	-60.60
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	Brownfield; New assets	594	727	397	26%	-65.96	-62.26
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	Brownfield; New assets	673	825	398	28%	-50.96	-49.51
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	Brownfield; New assets	609	746	390	25%	-138	-109
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	Brownfield; New assets	689	844	389	26%	-90.37	-79.04
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	Brownfield; New assets	547	671	382	26%	-80.86	-74.21
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	Brownfield; New assets	627	768	383	27%	-64.21	-60.80
8	Hlsarna wks, MDEA sep.	Brownfield; New assets	750	919	596	50%	156	86.06
8b	Hlsarna wks, MDEA sep. (BAT)	Brownfield; New assets	797	976	595	50%	142	82.70
8s	Hlsarna wks, max scrap, MDEA sep.	Brownfield; New assets	642	787	537	47%	84.17	53.76
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	688	843	536	48%	77.65	51.71
8.v	Hlsarna wks, VPSA sep.	Brownfield; New assets	733	898	587	50%	142	81.47
8b.v	Hlsarna wks, VPSA sep. (BAT)	Brownfield; New assets	780	955	586	51%	129	78.21
8s.v	Hlsarna wks, max scrap, VPSA sep.	Brownfield; New assets	629	771	530	47%	76.03	50.05
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	675	827	529	48%	70.21	48.11
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	Brownfield; New assets	669	819	409	26%	-37.41	-34.61
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	Brownfield; New assets	749	917	407	27%	-31.48	-30.08
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	Brownfield; New assets	594	727	397	26%	-40.27	-38.86
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	Brownfield; New assets	673	825	398	28%	-33.98	-33.33
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	Brownfield; New assets	609	746	390	25%	-56.10	-50.54
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	Brownfield; New assets	689	844	389	26%	-46.60	-43.39
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	Brownfield; New assets	547	671	382	26%	-51.56	-48.78
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	Brownfield; New assets	627	768	383	27%	-44.10	-42.47
8	Hlsarna wks, MDEA sep.	Brownfield; New assets	750	919	596	50%	88.38	60.44
8b	Hlsarna wks, MDEA sep. (BAT)	Brownfield; New assets	797	976	595	50%	83.31	58.63
8s	Hlsarna wks, max scrap, MDEA sep.	Brownfield; New assets	642	787	537	47%	55.71	40.53
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Brownfield; New assets	688	843	536	48%	52.62	39.27
8.v	Hlsarna wks, VPSA sep.	Brownfield; New assets	733	898	587	50%	81.40	57.14
8b.v	Hlsarna wks, VPSA sep. (BAT)	Brownfield; New assets	780	955	586	51%	76.74	55.37
8s.v	Hlsarna wks, max scrap, VPSA sep.	Brownfield; New assets	629	771	530	47%	50.78	37.71
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Brownfield; New assets	675	827	529	48%	47.96	36.50

Table A-29: Static economics of alternative site projects with alternative configuration, constructed for the UK iron and steel sector

ID	Description	Project	OPEX 2010 (average)	OPEX 2020 (average)	OPEX 2030 (average)	OPEX 2040 (average)	OPEX 2050 (average)	Production cost 2010	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Abatement cost 2010	Abatement cost 2020	Abatement cost 2030	Abatement cost 2040	Abatement cost 2050
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tCO$_2$e	£/tCO$_2$e	£/tCO$_2$e	£/tCO$_2$e	£/tCO$_2$e
0	Sector (Base)	Existing site modification	369	408	451	500	551	390	426	467	513	564					
0p	Sector (TP)	Existing site modification	355	391	433	478	527	378	412	451	495	542	-79.66	-101	-122	-146	-168
0p2	Sector (TP2)	Existing site modification	353	389	430	475	523	374	407	446	490	537	-101	-127	-152	-178	-202
0b	Sector (BAT)	Existing site modification	345	380	420	465	511	372	405	442	485	531	-87.12	-120	-153	-188	-217
1	Int.wks (Base)	Existing site modification	381	420	465	516	569	405	442	484	532	585					
1p	Int.wks (TP)	Existing site modification	365	402	444	492	542	398	433	473	518	567	-37.60	-53.74	-71.87	-92.32	-113
1b	Int.wks (BAT)	Existing site modification	357	393	434	480	529	396	430	469	513	561	-37.72	-59.66	-84.51	-112	-138
1s	Int.wks max scrap	Existing site modification	372	410	454	503	554	393	429	470	516	567	-29.12	-32.16	-35.69	-39.79	-44.29
1bs	Int.wks max scrap (BAT)	Existing site modification	352	388	428	473	520	387	420	458	501	548	-29.10	-37.39	-46.43	-56.52	-66.91
2	EAF wks (Base)	Existing site modification	327	361	400	442	486	334	366	402	443	487					
2p2	EAF wks (TP2)	Existing site modification	298	330	366	406	447	296	326	360	398	439	-456	-672	-878	-1,065	-1,131
2p	EAF wks (TP)	Existing site modification	318	351	388	429	472	334	365	400	439	482	3.23	-20.52	-57.80	-106	-153
2b	EAF wks (BAT)	Existing site modification	301	332	367	405	445	317	346	379	416	456	-146	-221	-299	-381	-440
3g	EAF gnf.wks	Greenfield	382	421	466	515	566	429	467	509	557	608	14.08	13.95	13.73	13.20	12.35
3gb	EAF gnf.wks (BAT)	Greenfield	365	403	445	492	540	417	453	493	539	587	7.00	6.18	4.98	3.28	1.09
4	Int.wks, MEA sep.	Existing site modification	438	486	542	605	672	485	530	582	642	708	77.79	83.74	92.07	102	115
4b	Int.wks, MEA sep. (BAT)	Existing site modification	402	444	491	545	601	461	500	545	596	652	40.59	41.76	43.36	45.37	47.72
4s	Int.wks, max scrap, MEA sep.	Existing site modification	417	463	515	573	635	456	498	547	603	664	41.97	45.69	50.54	56.45	63.31
4bs	Int.wks, max scrap, MEA sep. (BAT)	Existing site modification	388	427	473	524	577	438	475	518	568	619	22.47	22.56	22.74	23.00	23.32
5	TGR-BF wks, MDEA sep. w/o storage	Existing site modification	396	438	487	541	598	437	476	521	573	630	279	256	259	274	302
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	Existing site modification	378	415	459	507	558	432	468	508	555	605	87.75	80.10	73.72	67.51	61.53
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	Existing site modification	384	424	470	522	576	417	455	498	547	601	25.03	25.63	26.94	28.87	31.38
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	Existing site modification	369	405	447	494	544	415	450	489	534	583	16.09	12.23	7.85	2.87	-2.58
5.v	TGR-BF wks, VPSA sep. w/o storage	Existing site modification	383	422	467	516	569	418	455	497	544	596	59.80	51.20	46.74	43.57	41.55
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	Existing site modification	366	401	441	486	533	415	448	486	529	575	25.06	14.81	3.99	-8.23	-21.82
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	Existing site modification	373	411	454	503	553	403	438	479	525	575	-3.43	-5.82	-8.64	-11.91	-15.60
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	Existing site modification	358	392	432	475	521	401	433	470	512	557	-5.18	-11.17	-18.28	-26.63	-36.04
6	TGR-BF wks, MDEA sep.	Existing site modification	396	438	487	541	598	437	476	521	573	630	37.02	38.80	41.61	45.30	49.79
6b	TGR-BF wks, MDEA sep. (BAT)	Existing site modification	378	415	459	507	558	432	468	508	555	605	25.70	24.06	22.41	20.64	18.82
6s	TGR-BF wks, max scrap, MDEA sep.	Existing site modification	384	424	470	522	576	417	455	498	547	601	11.58	12.00	12.69	13.64	14.83
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	Existing site modification	369	405	447	494	544	415	450	489	534	583	8.56	6.53	4.20	1.53	-1.38
6.v	TGR-BF wks, VPSA sep.	Existing site modification	383	422	467	516	569	418	455	497	544	596	13.78	12.96	12.32	11.72	11.18
6b.v	TGR-BF wks, VPSA sep. (BAT)	Existing site modification	366	401	441	486	533	415	448	486	529	575	8.80	5.38	1.47	-3.06	-8.11
6s.v	TGR-BF wks, max scrap, VPSA sep.	Existing site modification	373	411	454	503	553	403	438	479	525	575	-1.72	-2.97	-4.44	-6.15	-8.05
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	Existing site modification	358	392	432	475	521	401	433	470	512	557	-2.91	-6.32	-10.39	-15.16	-20.51
7	Hlsarna wks	Existing site modification	281	309	341	377	415	329	355	385	420	457	-139	-168	-197	-229	-260
7b	Hlsarna wks (BAT)	Existing site modification	272	298	328	361	397	329	353	381	414	448	-127	-156	-186	-219	-251
7s	Hlsarna wks, max scrap	Existing site modification	290	318	351	388	426	328	355	386	420	458	-91.07	-105	-120	-137	-155
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	281	308	339	373	409	328	353	382	415	451	-84.26	-99.81	-117	-135	-155
8	Hlsarna wks, MDEA sep.	Existing site modification	321	352	387	425	466	388	416	449	486	526	-11.41	-16.44	-22.42	-29.38	-37.26
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	311	340	373	409	447	387	414	445	479	517	-11.48	-17.37	-24.33	-32.42	-41.51
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	323	354	389	428	469	375	404	438	475	516	-18.65	-23.00	-28.38	-34.76	-42.06
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	313	343	376	413	451	375	402	434	469	507	-18.11	-23.32	-29.63	-37.06	-45.48
8.v	Hlsarna wks, VPSA sep.	Existing site modification	315	345	380	418	459	376	405	438	474	514	-18.62	-23.75	-29.88	-36.99	-44.99
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	305	333	366	402	440	375	402	433	468	505	-18.37	-24.41	-31.55	-39.82	-49.04
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	318	348	383	422	463	367	396	429	466	506	-23.98	-28.47	-33.99	-40.50	-47.89
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	308	337	370	407	445	366	394	425	460	498	-23.22	-28.58	-35.05	-42.62	-51.14
9	MIDREX wks	Existing site modification	341	382	430	484	542	388	426	470	522	579	-13.46	-12.88	-11.32	-8.70	-5.21
9g	MIDREX gnf.wks	Greenfield	336	376	423	477	533	437	475	520	571	627	25.62	26.80	28.49	30.94	33.79
9b	MIDREX wks (BAT)	Existing site modification	324	362	406	456	510	379	414	455	503	556	-19.30	-20.88	-21.93	-22.44	-22.41
9.i	MIDREX wks, imp.elec.	Existing site modification	353	392	436	486	538	393	429	470	518	570	-9.29	-9.50	-9.91	-10.32	-10.76
9g.i	MIDREX gnf.wks, imp.elec.	Greenfield	352	391	435	484	536	439	475	517	565	616	26.87	24.78	23.61	22.84	22.34
9b.i	MIDREX wks, imp.elec. (BAT)	Existing site modification	333	369	411	458	507	383	416	455	500	549	-16.22	-17.88	-19.94	-22.24	-24.79
10	MIDREX wks MDEA sep.	Existing site modification	360	403	455	513	575	418	459	506	562	623	7.76	10.11	13.39	17.77	23.00
10g	MIDREX gnf.wks MDEA sep.	Greenfield	354	398	448	506	567	471	512	559	614	675	38.78	41.44	44.76	48.98	53.71
10b	MIDREX wks MDEA sep. (BAT)	Existing site modification	341	381	429	483	540	406	444	488	539	596	0.76	1.25	2.33	4.12	6.49
10.v	MIDREX wks VPSA sep.	Existing site modification	351	393	443	499	558	406	445	491	545	603	0.77	2.08	4.14	7.07	10.68
10g.v	MIDREX gnf.wks VPSA sep.	Greenfield	346	387	436	491	550	458	498	543	596	654	29.92	31.51	33.60	36.38	39.54
10b.v	MIDREX wks VPSA sep. (BAT)	Existing site modification	333	372	418	470	525	395	432	474	524	578	-5.16	-5.51	-5.42	-4.81	-3.75
11	ULCORED wks, NG, MDEA sep.	Existing site modification	351	393	442	497	557	412	451	496	549	607	4.00	5.21	7.12	9.86	13.28
11g	ULCORED gnf.wks, NG, MDEA sep.	Greenfield	346	387	436	490	548	468	507	552	605	662	35.87	37.42	39.38	42.01	44.98
11b	ULCORED wks, NG, MDEA sep. (BAT)	Existing site modification	332	371	416	467	521	400	436	478	526	580	-2.82	-3.40	-3.61	-3.35	-2.68
11.v	ULCORED wks, NG, VPSA sep.	Existing site modification	343	383	430	484	541	400	438	482	533	589	-2.33	-2.02	-1.18	0.29	2.28
11g.v	ULCORED gnf.wks, NG, VPSA sep.	Greenfield	337	377	424	476	532	455	493	537	587	642	27.65	28.24	29.11	30.45	32.02
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	Existing site modification	324	362	406	455	507	390	424	465	512	564	-8.12	-9.43	-10.49	-11.25	-11.72
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	Existing site modification	364	403	448	498	551	411	447	489	537	590	4.10	3.54	3.19	2.98	2.91
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	Greenfield	359	397	441	490	543	455	492	533	581	633	33.46	31.03	29.75	28.92	28.43
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	Existing site modification	342	378	420	467	517	399	433	472	517	566	-3.59	-5.20	-6.98	-8.90	-10.98
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	Existing site modification	357	394	437	485	535	402	437	477	523	573	-1.69	-2.81	-4.09	-5.52	-7.11
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	Greenfield	352	388	430	477	527	445	480	519	565	614	25.49	22.56	20.37	18.34	16.35
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	Existing site modification	336	371	411	456	503	391	424	461	504	550	-8.38	-10.50	-13.06	-16.00	-19.33
12	ULCORED wks, coal, MDEA sep.	Existing site modification	361	403	451	505	563	437	476	521	573	630	20.71	22.13	24.01	26.54	29.56
12g	ULCORED gnf.wks, coal, MDEA sep.	Greenfield	357	399	447	501	558	503	541	587	638	695	60.22	62.21	64.33	66.89	69.59
12b	ULCORED wks, coal, MDEA sep. (BAT)	Existing site modification	342	380	425	475	528	425	461	503	550	603	12.69	12.11	11.65	11.44	11.44
12.v	ULCORED wks, coal, VPSA sep.	Existing site modification	344	382	427	477	530	414	450	491	539	592	5.40	4.79	4.32	4.08	4.04
12g.v	ULCORED gnf.wks, coal, VPSA sep.	Greenfield	339	377	421	470	522	477	513	554	602	653	41.38	41.15	40.75	40.39	39.92
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	Existing site modification	326	361	402	448	497	403	436	474	518	566	-0.84	-3.11	-5.54	-8.08	-10.65
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	Existing site modification	376	414	458	506	556	436	472	513	559	609	24.63	21.68	19.73	17.96	16.38
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	Greenfield	372	410	453	501	551	487	523	563	609	659	63.23	57.06	53.70	51.15	49.32
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	Existing site modification	354	390	430	475	523	424	458	496	539	586	14.32	10.93	7.71	4.22	0.48
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	Existing site modification	362	398	435	478	523	416	449	485	527	572	8.03	4.47	0.82	-3.37	-8.14
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	Greenfield	357	391	429	472	516	468	500	536	577	621	43.88	37.12	31.99	26.91	21.75
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	Existing site modification	341	373	409	449	491	405	435	469	508	549	0.11	-4.05	-8.84	-14.47	-20.98
13	ULCORED wks, exs coal syng., MDEA sep.	Existing site modification	402	448	502	564	628	504	547	598	656	720	64.09	69.31	75.19	82.15	89.81
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	Greenfield	396	442	496	557	621	568	611	662	720	784	102	108	114	121	128
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	Existing site modification	382	426	476	533	593	492	532	579	633	693	54.45	57.47	60.81	64.80	69.20
13.v	ULCORED wks, exs coal syng., VPSA sep.	Existing site modification	378	421	471	526	585	466	506	552	605	664	36.39	38.62	41.18	44.29	47.76
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	Greenfield	370	412	461	516	574	528	567	613	666	723	72.58	75.17	77.76	80.69	83.64
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	Existing site modification	357	396	442	492	546	452	489	531	579	632	27.74	27.87	27.97	28.19	28.50
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	Existing site modification	421	463	511	564	620	503	542	587	638	693	83.28	75.39	73.20	72.96	74.74
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	Greenfield	417	459	506	559	614	557	596	641	692	747	128	115	110	109	111
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	Existing site modification	399	439	484	533	585	491	528	570	618	669	67.37	61.09	58.30	56.58	55.98
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	Existing site modification	384	420	462	508	556	457	492	531	576	623	37.18	32.85	29.75	26.73	23.81
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	Greenfield	378	415	456	502	550	521	555	595	639	687	81.13	73.85	69.50	65.80	62.73
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	Existing site modification	361	396	435	479	525	445	478	515	557	603	27.08	23.05	19.29	15.19	10.80
14	ULCORED wks, bio., MDEA sep.	Existing site modification	452	488	530	577	627	527	561	599	644	693	51.20	50.24	48.99	47.65	46.24
14g	ULCORED gnf.wks, bio., MDEA sep.	Greenfield	449	485	526	572	622	595	628	667	712	761	77.75	77.08	75.98	74.70	73.17
14b	ULCORED wks, bio., MDEA sep. (BAT)	Existing site modification	433	466	504	546	592	515	546	581	622	666	45.24	43.02	40.30	37.25	33.93
14.v	ULCORED wks, bio., VPSA sep.	Existing site modification	436	469	507	550	595	506	536	572	613	658	39.79	37.68	35.10	32.20	29.06
14g.v	ULCORED gnf.wks, bio., VPSA sep.	Greenfield	433	466	503	546	591	573	604	639	680	724	66.00	64.17	61.73	58.90	55.67
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	Existing site modification	420	450	485	524	565	496	525	557	595	635	35.72	32.62	28.89	24.64	20.01
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	Existing site modification	467	499	536	577	620	526	557	592	631	673	57.61	51.78	47.17	42.64	38.26
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	Greenfield	463	496	532	572	615	579	609	644	683	725	81.93	74.86	69.66	64.79	60.26
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	Existing site modification	445	475	509	547	586	514	542	574	610	649	49.66	43.88	38.60	33.05	27.32
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	Existing site modification	455	484	517	554	592	509	537	568	604	641	47.17	40.71	35.08	29.21	23.15
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	Greenfield	450	479	512	547	585	562	590	621	655	692	70.37	62.59	56.28	49.96	43.63
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	Existing site modification	434	461	491	525	560	498	524	552	585	619	40.44	33.99	27.76	21.00	13.78
15	ULCORED wks, exs bio.syng., MDEA sep.	Existing site modification	593	626	665	708	754	692	723	760	801	847	86.22	85.12	83.52	81.64	79.50
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	Greenfield	592	626	665	709	756	765	797	834	876	923	107	107	105	104	102
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	Existing site modification	577	608	644	685	727	684	713	746	785	827	83.19	81.41	79.02	76.21	73.06
15.v	ULCORED wks, exs bio.syng., VPSA sep.	Existing site modification	578	610	646	686	729	665	694	728	767	809	76.81	75.09	72.78	70.08	67.04
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	Greenfield	567	596	630	669	709	727	755	787	824	864	94.83	92.86	90.17	86.93	83.20
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	Existing site modification	555	583	614	649	686	649	674	704	737	774	71.70	68.87	65.25	61.01	56.25
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	Existing site modification	615	645	679	716	754	694	723	755	790	829	98.34	90.83	85.45	80.48	76.03
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	Greenfield	611	641	674	711	749	752	781	812	848	886	117	109	103	97.97	93.43
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	Existing site modification	593	621	651	685	720	682	708	738	770	805	91.18	84.10	78.40	72.78	67.33
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	Existing site modification	583	609	638	670	703	657	682	709	740	773	80.42	74.05	68.44	62.62	56.72
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	Greenfield	577	603	632	663	696	723	747	775	805	838	101	94.02	88.19	82.22	76.21
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	Existing site modification	558	582	609	638	669	643	666	691	719	750	73.77	68.03	62.28	56.00	49.33
16	ULCOWIN wks, imp.elec.	Existing site modification	519	566	617	674	732	569	613	662	717	775	220	139	121	115	119
16g	ULCOWIN gnf.wks, imp.elec.	Greenfield	514	559	610	665	723	612	656	705	758	816	269	170	147	139	142
16b	ULCOWIN wks, imp.elec. (BAT)	Existing site modification	497	541	589	642	697	556	598	644	695	750	179	119	104	98.53	99.78

Table A-30: Dynamic economics of technology sites constructed for the UK iron and steel sector

ID	Description	Project	OPEX 2010 (average)	OPEX 2020 (average)	OPEX 2030 (average)	OPEX 2040 (average)	OPEX 2050 (average)	Production cost 2010	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Abatement cost 2010	Abatement cost 2020	Abatement cost 2030	Abatement cost 2040	Abatement cost 2050
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tCO_2e	£/tCO_2e	£/tCO_2e	£/tCO_2e	£/tCO_2e
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	Existing site modification	388	428	475	527	583	428	466	510	560	615	86.47	84.37	86.51	91.18	98.40
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	Existing site modification	369	406	448	494	543	423	458	497	542	590	40.04	33.17	26.24	18.74	10.78
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	Existing site modification	377	416	461	511	564	411	447	489	537	590	9.39	8.61	8.02	7.61	7.37
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT	Existing site modification	362	398	438	484	531	409	442	480	524	571	4.89	0.36	-4.86	-10.85	-17.46
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	Existing site modification	374	412	455	503	554	410	445	486	532	582	12.99	8.05	3.29	-1.80	-7.31
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	Existing site modification	357	391	430	472	517	406	438	474	515	560	2.48	-6.39	-16.52	-28.25	-41.51
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	Existing site modification	366	403	445	492	541	396	430	470	515	564	-12.23	-15.34	-19.12	-23.57	-28.61
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT	Existing site modification	351	385	423	465	509	394	425	461	501	545	-12.24	-18.42	-25.84	-34.57	-44.44
6.2	TGR-BF [V4] wks, MDEA sep.	Existing site modification	388	428	475	527	583	428	466	510	560	615	23.03	23.62	24.77	26.41	28.50
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	Existing site modification	369	406	448	494	543	423	458	497	542	590	15.39	12.98	10.36	7.43	4.28
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	Existing site modification	377	416	461	511	564	411	447	489	537	590	4.86	4.49	4.21	4.00	3.67
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	Existing site modification	362	398	438	484	531	409	442	480	524	571	2.81	0.21	-2.81	-6.28	-10.10
6.2.v	TGR-BF [V4] wks, VPSA sep.	Existing site modification	374	412	455	503	554	410	445	486	532	582	4.39	2.85	1.19	-0.66	-2.68
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	Existing site modification	357	391	430	472	517	406	438	474	515	560	1.07	-2.82	-7.36	-12.65	-18.60
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	Existing site modification	366	403	445	492	541	396	430	470	515	564	-6.72	-8.53	-10.70	-13.22	-16.05
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	Existing site modification	351	385	423	465	509	394	425	461	501	545	-7.34	-11.13	-15.66	-20.98	-26.97
7	Hlsarna wks	Existing site modification	523	544	568	594	622	574	594	616	641	669	87.82	80.03	69.99	58.06	44.68
7b	Hlsarna wks (BAT)	Existing site modification	514	533	555	579	604	573	592	612	635	661	84.95	76.74	66.09	53.42	39.19
7s	Hlsarna wks, max scrap	Existing site modification	477	501	527	556	587	518	540	564	593	623	58.86	51.48	42.45	31.88	20.15
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	468	490	515	542	570	518	538	561	587	616	56.78	49.18	39.66	28.41	15.87
8	Hlsarna wks, MDEA sep.	Existing site modification	565	589	615	645	676	635	657	683	711	741	78.53	72.29	65.99	59.11	51.81
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	555	577	601	628	657	634	655	678	704	732	76.16	69.86	63.20	55.81	47.86
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	512	537	566	598	631	567	591	619	649	682	60.48	54.74	48.80	42.23	35.19
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	502	526	553	583	614	567	589	615	644	674	58.71	52.80	46.46	39.34	31.62
8.v	Hlsarna wks, VPSA sep.	Existing site modification	558	581	608	637	668	623	645	670	699	729	74.06	68.22	62.05	55.19	47.84
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	548	569	594	621	649	622	643	666	692	720	71.80	65.86	59.31	51.93	43.91
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	506	532	560	592	625	558	582	609	640	673	56.75	51.27	45.40	38.83	31.73
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	497	520	547	577	608	558	580	605	634	664	55.08	49.41	43.12	35.99	28.21
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	Existing site modification	350	391	437	490	545	391	429	473	523	577	-51.25	-44.25	-38.15	-31.47	-24.24
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	Existing site modification	332	368	410	457	506	386	420	459	504	553	-40.04	-44.56	-50.42	-57.35	-65.31
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	Existing site modification	348	387	432	482	535	381	418	460	508	561	-37.22	-37.15	-37.34	-37.54	-37.78
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	Existing site modification	333	368	409	454	502	379	413	451	494	542	-32.10	-36.29	-41.36	-47.26	-53.87
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	Existing site modification	337	374	417	466	516	372	407	448	494	544	-85.11	-83.01	-84.74	-88.30	-93.81
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	Existing site modification	320	353	392	435	480	368	400	437	477	522	-63.73	-69.87	-78.77	-89.85	-103
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	Existing site modification	337	374	416	463	512	367	401	441	486	534	-53.21	-55.22	-58.50	-62.68	-67.72
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	Existing site modification	322	356	393	435	480	365	396	432	472	516	-45.60	-51.21	-58.37	-66.96	-76.83
8	Hlsarna wks, MDEA sep.	Existing site modification	506	530	557	586	617	576	599	624	652	683	97.54	86.75	76.22	64.90	52.97
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	496	518	543	570	598	575	596	619	645	674	92.86	82.27	71.38	59.38	46.53
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	466	492	521	553	586	522	546	573	604	637	65.85	57.11	48.21	38.43	27.95
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	457	481	508	537	568	521	544	569	598	629	62.99	54.16	44.77	34.28	22.89
8.v	Hlsarna wks, VPSA sep.	Existing site modification	499	523	549	579	609	565	587	612	640	670	89.92	80.02	69.78	58.51	46.46
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	489	511	535	562	590	564	584	607	633	661	85.57	75.75	65.09	53.13	40.15
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	461	486	515	547	580	513	537	564	594	627	60.18	51.90	43.12	33.34	22.75
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	451	475	502	531	562	512	535	560	588	619	57.56	49.12	39.83	29.31	17.82
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	Existing site modification	350	391	437	490	545	391	429	473	523	577	-18.07	-16.30	-14.33	-11.94	-9.20
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	Existing site modification	332	368	410	457	506	386	420	459	504	553	-19.36	-21.88	-24.93	-28.47	-32.42
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	Existing site modification	348	387	432	482	535	381	418	460	508	561	-22.95	-23.07	-23.27	-23.43	-23.58
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	Existing site modification	333	368	409	454	502	379	413	451	494	542	-21.50	-24.38	-27.82	-31.82	-36.26
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	Existing site modification	337	374	417	466	516	372	407	448	494	544	-36.88	-37.49	-38.98	-41.01	-43.56
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	Existing site modification	320	353	392	435	480	368	400	437	477	522	-33.85	-37.84	-43.04	-49.33	-56.61
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	Existing site modification	337	374	416	463	512	367	401	441	486	534	-34.41	-36.05	-38.36	-41.19	-44.51
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	Existing site modification	322	356	393	435	480	365	396	432	472	516	-31.56	-35.63	-40.71	-46.77	-53.66
8	Hlsarna wks, MDEA sep.	Existing site modification	506	530	557	586	617	576	599	624	652	683	67.53	60.57	53.43	45.58	37.20
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	496	518	543	570	598	575	596	619	645	674	65.14	58.07	50.52	42.10	32.99
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	466	492	521	553	586	522	546	573	604	637	49.10	42.86	36.29	28.98	21.08
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	457	481	508	537	568	521	544	569	598	629	47.44	40.99	33.96	26.03	17.38
8.v	Hlsarna wks, VPSA sep.	Existing site modification	499	523	549	579	609	565	587	612	640	670	62.46	55.90	48.87	41.04	32.58
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	489	511	535	562	590	564	584	607	633	661	60.21	53.49	46.04	37.61	28.42
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	461	486	515	547	580	513	537	564	594	627	44.96	38.96	32.45	25.12	17.14
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	451	475	502	531	562	512	535	560	588	619	43.44	37.19	30.20	22.24	13.52

Table A-31: Dynamic economics of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	Cost of EUETS, 50£/tCO2	Cost of EUETS, 100£/tCO2	Cost of EUETS, 200£/tCO2
		£/tcs	£/tcs	£/tcs
0	Sector (Base)	82.01	164	328
0p	Sector (TP)	75.75	152	303
0p2	Sector (TP2)	75.70	151	303
0b	Sector (BAT)	75.11	150	300
1	Int.wks (Base)	101	203	405
1p	Int.wks (TP)	93.64	187	375
1b	Int.wks (BAT)	93.28	187	373
1s	Int.wks max scrap	81.11	162	324
1bs	Int.wks max scrap (BAT)	74.47	149	298
2	EAF wks (Base)	8.65	17.29	34.58
2p2	EAF wks (TP2)	7.78	15.57	31.13
2p	EAF wks (TP)	7.47	14.95	29.89
2b	EAF wks (BAT)	5.85	11.71	23.41
3g	EAF gnf.wks	7.46	14.91	29.83
3gb	EAF gnf.wks (BAT)	6.56	13.11	26.23
4	Int.wks, MEA sep.	47.08	94.15	188
4b	Int.wks, MEA sep. (BAT)	31.09	62.19	124
4s	Int.wks, max scrap, MEA sep.	38.40	76.79	154
4bs	Int.wks, max scrap, MEA sep. (BAT)	27.49	54.97	110
5	TGR-BF wks, MDEA sep. w/o storage	93.55	187	374
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	84.39	169	338
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	75.12	150	300
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	67.63	135	271
5.v	TGR-BF wks, VPSA sep. w/o storage	86.86	174	347
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	78.42	157	314
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	69.91	140	280
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	62.43	125	250
6	TGR-BF wks, MDEA sep.	55.93	112	224
6b	TGR-BF wks, MDEA sep. (BAT)	46.77	93.53	187
6s	TGR-BF wks, max scrap, MDEA sep.	45.95	91.89	184
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	38.45	76.90	154
6.v	TGR-BF wks, VPSA sep.	49.24	98.48	197
6b.v	TGR-BF wks, VPSA sep. (BAT)	40.80	81.60	163
6s.v	TGR-BF wks, max scrap, VPSA sep.	40.73	81.47	163
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	33.25	66.50	133
7	Hlsarna wks	77.69	155	311
7b	Hlsarna wks (BAT)	75.26	151	301
7s	Hlsarna wks, max scrap	61.36	123	245
7bs	Hlsarna wks, max scrap (BAT)	59.09	118	236
8	Hlsarna wks, MDEA sep.	21.50	42.99	85.99
8b	Hlsarna wks, MDEA sep. (BAT)	18.75	37.51	75.01
8s	Hlsarna wks, max scrap, MDEA sep.	17.85	35.69	71.39
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	15.26	30.51	61.03
8.v	Hlsarna wks, VPSA sep.	22.34	44.68	89.36
8b.v	Hlsarna wks, VPSA sep. (BAT)	19.59	39.19	78.38
8s.v	Hlsarna wks, max scrap, VPSA sep.	18.50	37.00	74.00
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	15.91	31.82	63.64
9	MIDREX wks	41.83	83.66	167
9g	MIDREX gnf.wks	40.64	81.28	163
9b	MIDREX wks (BAT)	37.21	74.42	149
9.i	MIDREX wks, imp.elec.	29.49	58.97	118
9g.i	MIDREX gnf.wks, imp.elec.	29.16	58.32	117
9b.i	MIDREX wks, imp.elec. (BAT)	27.70	55.39	111
10	MIDREX wks MDEA sep.	19.82	39.63	79.27
10g	MIDREX gnf.wks MDEA sep.	18.69	37.38	74.76
10b	MIDREX wks MDEA sep. (BAT)	17.20	34.40	68.79
10.v	MIDREX wks VPSA sep.	15.82	31.63	63.27
10g.v	MIDREX gnf.wks VPSA sep.	14.70	29.40	58.81
10b.v	MIDREX wks VPSA sep. (BAT)	13.56	27.12	54.24
11	ULCORED wks, NG, MDEA sep.	17.65	35.30	70.60
11g	ULCORED gnf.wks, NG, MDEA sep.	16.53	33.06	66.11
11b	ULCORED wks, NG, MDEA sep. (BAT)	15.16	30.31	60.63
11.v	ULCORED wks, NG, VPSA sep.	13.80	27.60	55.21
11g.v	ULCORED gnf.wks, NG, VPSA sep.	12.69	25.38	50.76
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	11.70	23.40	46.79
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	16.12	32.25	64.49
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	15.01	30.02	60.04
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	13.93	27.86	55.73
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	12.17	24.35	48.69
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	11.07	22.15	44.29
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	10.38	20.77	41.54
12	ULCORED wks, coal, MDEA sep.	25.68	51.37	103
12g	ULCORED gnf.wks, coal, MDEA sep.	23.05	46.10	92.20
12b	ULCORED wks, coal, MDEA sep. (BAT)	23.19	46.38	92.76
12.v	ULCORED wks, coal, VPSA sep.	17.67	35.35	70.69
12g.v	ULCORED gnf.wks, coal, VPSA sep.	16.56	33.12	66.25
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	15.57	31.14	62.27
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	23.88	47.76	95.52
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	23.05	46.10	92.21
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	21.69	43.38	86.76
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	15.66	31.32	62.64
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	14.56	29.12	58.24
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	13.87	27.74	55.48
13	ULCORED wks, exs coal syng., MDEA sep.	26.94	53.87	108
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	24.47	48.95	97.90
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	24.53	49.06	98.11
13.v	ULCORED wks, exs coal syng., VPSA sep.	19.78	39.56	79.11
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	19.68	39.36	78.72
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	19.10	38.19	76.39
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	24.63	49.25	98.50
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	23.82	47.64	95.29
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	22.52	45.05	90.09
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	17.49	34.99	69.98
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	17.56	35.13	70.26
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	17.41	34.83	69.66
14	ULCORED wks, bio., MDEA sep.	-15.02	-30.03	-60.06
14g	ULCORED gnf.wks, bio., MDEA sep.	-17.89	-35.79	-71.57
14b	ULCORED wks, bio., MDEA sep. (BAT)	-17.51	-35.02	-70.04
14.v	ULCORED wks, bio., VPSA sep.	-22.55	-45.10	-90.20
14g.v	ULCORED gnf.wks, bio., VPSA sep.	-22.93	-45.87	-91.73
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	-23.93	-47.85	-95.71
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	-16.77	-33.54	-67.08
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	-17.55	-35.10	-70.20
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	-18.96	-37.92	-75.84
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	-23.75	-47.51	-95.01
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	-24.85	-49.71	-99.41
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	-25.54	-51.09	-102
15	ULCORED wks, exs bio.syng., MDEA sep.	-62.20	-124	-249
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	-63.36	-127	-253
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	-63.07	-126	-252
15.v	ULCORED wks, exs bio.syng., VPSA sep.	-64.96	-130	-260
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	-65.23	-130	-261
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	-65.70	-131	-263
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	-62.72	-125	-251
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	-63.47	-127	-254
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	-64.97	-130	-260
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	-66.99	-134	-268
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	-66.94	-134	-268
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	-67.07	-134	-268
16	ULCOWIN wks, imp.elec.	8.39	16.78	33.57
16g	ULCOWIN gnf.wks, imp.elec.	7.19	14.39	28.78
16b	ULCOWIN wks, imp.elec. (BAT)	6.29	12.59	25.18

Table A-32: Emissions trading costs of technology sites constructed for the UK iron and steel sector

ID	Description	Cost of EUETS, 50£/tCO₂	Cost of EUETS, 100£/tCO₂	Cost of EUETS, 200£/tCO₂
		£/tcs	£/tcs	£/tcs
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	85.68	171	343
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	76.19	152	305
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	68.96	138	276
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	61.07	122	244
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	78.99	158	316
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	70.09	140	280
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	63.75	127	255
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	55.87	112	223
6.2	TGR-BF [V4] wks, MDEA sep.	48.06	96.13	192
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	38.57	77.13	154
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	39.78	79.57	159
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	31.89	63.78	128
6.2.v	TGR-BF [V4] wks, VPSA sep.	41.37	82.74	165
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	32.47	64.95	130
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	34.57	69.14	138
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	26.69	53.38	107
7	Hlsarna wks	8.41	16.81	33.62
7b	Hlsarna wks (BAT)	5.98	11.95	23.90
7s	Hlsarna wks, max scrap	7.63	15.25	30.50
7bs	Hlsarna wks, max scrap (BAT)	5.35	10.70	21.40
8	Hlsarna wks, MDEA sep.	-50.86	-102	-203
8b	Hlsarna wks, MDEA sep. (BAT)	-53.60	-107	-214
8s	Hlsarna wks, max scrap, MDEA sep.	-38.27	-76.54	-153
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	-40.86	-81.72	-163
8.v	Hlsarna wks, VPSA sep.	-49.97	-99.94	-200
8b.v	Hlsarna wks, VPSA sep. (BAT)	-52.71	-105	-211
8s.v	Hlsarna wks, max scrap, VPSA sep.	-37.58	-75.16	-150
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	-40.17	-80.34	-161
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	85.68	171	343
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	76.19	152	305
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	68.96	138	276
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	61.07	122	244
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	78.99	158	316
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	70.09	140	280
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	63.75	127	255
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	55.87	112	223
8	Hlsarna wks, MDEA sep.	7.83	15.65	31.31
8b	Hlsarna wks, MDEA sep. (BAT)	5.08	10.17	20.33
8s	Hlsarna wks, max scrap, MDEA sep.	7.25	14.49	28.98
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	4.65	9.31	18.62
8.v	Hlsarna wks, VPSA sep.	8.72	17.43	34.86
8b.v	Hlsarna wks, VPSA sep. (BAT)	5.97	11.94	23.88
8s.v	Hlsarna wks, max scrap, VPSA sep.	7.93	15.87	31.74
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	5.34	10.69	21.38
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	60.60	121	242
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	51.11	102	204
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	49.51	99.02	198
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	41.62	83.23	166
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	53.91	108	216
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	45.01	90.03	180
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	44.30	88.60	177
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	36.41	72.83	146
8	Hlsarna wks, MDEA sep.	-31.30	-62.59	-125
8b	Hlsarna wks, MDEA sep. (BAT)	-34.04	-68.08	-136
8s	Hlsarna wks, max scrap, MDEA sep.	-23.10	-46.20	-92.39
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	-25.69	-51.38	-103
8.v	Hlsarna wks, VPSA sep.	-30.41	-60.81	-122
8b.v	Hlsarna wks, VPSA sep. (BAT)	-33.15	-66.30	-133
8s.v	Hlsarna wks, max scrap, VPSA sep.	-22.41	-44.82	-89.64
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	-25.00	-50.00	-100.00

Table A-33: Emissions trading costs of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	Project	2010-2050 trading price, 0-50£/tCO$_2$				2010-2050 trading price, 0-100£/tCO$_2$				2010-2050 trading price, 0-200£/tCO$_2$			
			Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs
0	Sector (Base)	Existing site modification	462	523	591	662	498	580	668	760	570	693	822	956
0p	Sector (TP)	Existing site modification	445	503	566	633	478	555	637	724	545	660	780	905
0p2	Sector (TP2)	Existing site modification	441	498	561	628	474	551	633	718	541	656	776	899
0b	Sector (BAT)	Existing site modification	438	494	555	621	471	546	626	710	537	650	768	890
1	Int.wks (Base)	Existing site modification	486	554	628	706	531	624	723	827	620	764	914	1,069
1p	Int.wks (TP)	Existing site modification	474	538	606	679	515	602	695	791	598	732	872	1,016
1b	Int.wks (BAT)	Existing site modification	471	533	601	672	512	598	689	784	594	727	865	1,007
1s	Int.wks max scrap	Existing site modification	464	526	593	664	500	582	669	761	571	694	822	955
1bs	Int.wks max scrap (BAT)	Existing site modification	453	510	572	637	486	561	642	726	551	665	783	905
2	EAF wks (Base)	Existing site modification	370	408	451	497	374	415	460	508	382	427	477	530
2p2	EAF wks (TP2)	Existing site modification	330	366	406	449	333	371	413	458	340	382	427	476
2p	EAF wks (TP)	Existing site modification	368	406	447	491	372	411	454	501	379	422	470	520
2b	EAF wks (BAT)	Existing site modification	349	384	422	463	352	388	428	471	357	397	440	486
3g	EAF gnf.wks	Greenfield	470	515	564	617	474	520	571	626	481	531	586	645
3gb	EAF gnf.wks (BAT)	Greenfield	456	498	545	595	459	503	551	603	465	513	564	620
4	Int.wks, MEA sep.	Existing site modification	551	615	687	764	571	648	732	821	613	713	821	935
4b	Int.wks, MEA sep. (BAT)	Existing site modification	514	567	626	689	528	588	655	727	555	632	715	803
4s	Int.wks, max scrap, MEA sep.	Existing site modification	515	574	639	710	532	601	676	757	566	654	749	849
4bs	Int.wks, max scrap, MEA sep. (BAT)	Existing site modification	487	537	593	653	499	556	619	686	524	595	672	753
5	TGR-BF wks, MDEA sep. w/o storage	Existing site modification	517	586	661	741	558	651	749	853	640	780	925	1,076
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	Existing site modification	505	567	634	706	542	625	714	807	616	742	874	1,009
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	Existing site modification	488	550	618	691	521	602	689	781	587	706	830	960
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	Existing site modification	480	536	598	664	509	583	662	745	569	677	790	907
5.v	TGR-BF wks, VPSA sep. w/o storage	Existing site modification	493	557	626	700	531	617	708	804	607	737	872	1,011
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	Existing site modification	483	540	603	669	517	595	677	763	586	703	825	951
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	Existing site modification	469	527	591	659	500	575	657	742	561	672	788	909
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	Existing site modification	461	513	571	632	488	557	630	707	543	643	748	857
6	TGR-BF wks, MDEA sep.	Existing site modification	501	560	626	697	525	599	679	764	575	676	784	898
6b	TGR-BF wks, MDEA sep. (BAT)	Existing site modification	488	541	599	662	509	574	644	718	550	639	733	831
6s	TGR-BF wks, max scrap, MDEA sep.	Existing site modification	475	530	591	656	495	562	634	711	536	625	721	821
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	Existing site modification	467	516	571	630	484	543	608	676	518	597	681	769
6.v	TGR-BF wks, VPSA sep.	Existing site modification	476	531	591	655	498	565	638	714	542	633	731	832
6b.v	TGR-BF wks, VPSA sep. (BAT)	Existing site modification	466	514	568	624	484	543	606	674	521	600	684	772
6s.v	TGR-BF wks, max scrap, VPSA sep.	Existing site modification	456	507	563	624	474	535	602	673	510	592	679	771
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	Existing site modification	448	493	544	597	463	517	575	638	492	563	639	718
7	Hlsarna wks	Existing site modification	389	439	493	549	424	493	566	642	492	600	712	828
7b	Hlsarna wks (BAT)	Existing site modification	386	433	484	538	419	485	555	628	485	589	697	808
7s	Hlsarna wks, max scrap	Existing site modification	382	428	478	532	409	470	536	605	463	555	652	752
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	379	423	471	522	405	464	527	592	457	546	638	734
8	Hlsarna wks, MDEA sep.	Existing site modification	426	464	507	552	435	479	527	578	455	509	588	630
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	422	458	497	540	431	471	516	563	447	498	552	609
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	412	450	492	537	420	463	509	559	436	488	543	602
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	409	445	484	526	416	456	499	545	430	477	528	582
8.v	Hlsarna wks, VPSA sep.	Existing site modification	415	453	496	542	425	469	517	569	445	500	560	623
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	411	447	486	529	420	461	505	553	438	488	543	601
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	404	442	484	529	412	455	501	551	429	481	537	596
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	401	436	475	518	408	447	491	537	422	470	522	576
9	MIDREX wks	Existing site modification	444	499	561	629	463	528	601	678	499	586	679	778
9g	MIDREX gnf.wks	Greenfield	494	548	609	676	512	577	648	725	549	634	726	823
9b	MIDREX wks (BAT)	Existing site modification	430	481	538	600	447	507	573	645	479	558	643	733
9.i	MIDREX wks, imp.elec.	Existing site modification	442	491	546	605	455	511	574	640	481	552	629	711
9g.i	MIDREX gnf.wks, imp.elec.	Greenfield	489	538	593	652	502	558	621	687	528	600	677	758
9b.i	MIDREX wks, imp.elec. (BAT)	Existing site modification	429	475	526	582	441	494	552	615	465	532	605	681
10	MIDREX wks MDEA sep.	Existing site modification	467	520	580	647	476	534	599	671	494	561	637	718
10g	MIDREX gnf.wks MDEA sep.	Greenfield	520	573	632	698	529	586	650	720	546	613	686	766
10b	MIDREX wks MDEA sep. (BAT)	Existing site modification	451	500	556	617	459	512	572	637	474	536	605	679
10.v	MIDREX wks VPSA sep.	Existing site modification	452	502	560	622	459	513	575	642	473	535	605	680
10g.v	MIDREX gnf.wks VPSA sep.	Greenfield	504	554	610	672	511	564	625	690	525	585	653	726
10b.v	MIDREX wks VPSA sep. (BAT)	Existing site modification	438	484	537	595	444	493	550	611	456	512	575	644
11	ULCORED wks, NG, MDEA sep.	Existing site modification	458	509	566	629	466	521	583	650	482	545	616	692
11g	ULCORED gnf.wks, NG, MDEA sep.	Greenfield	514	564	620	682	522	576	636	703	537	599	668	743
11b	ULCORED wks, NG, MDEA sep. (BAT)	Existing site modification	442	488	541	599	449	499	555	617	463	520	584	653
11.v	ULCORED wks, NG, VPSA sep.	Existing site modification	444	492	546	606	450	501	559	622	463	521	585	656
11g.v	ULCORED gnf.wks, NG, VPSA sep.	Greenfield	499	546	599	658	505	555	612	673	516	573	636	705
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	Existing site modification	430	473	523	578	435	481	534	592	445	498	557	620
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	Existing site modification	454	501	553	609	462	512	568	629	476	534	599	667
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	Greenfield	499	544	595	651	505	555	610	669	519	576	639	706
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	Existing site modification	439	482	530	583	445	492	544	600	458	511	570	633
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	Existing site modification	442	486	534	587	448	494	546	602	459	511	569	632
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	Greenfield	485	527	575	627	490	535	586	641	500	551	608	668
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	Existing site modification	428	468	514	563	433	476	524	576	442	490	544	601
12	ULCORED wks, coal, MDEA sep.	Existing site modification	487	539	597	661	499	557	622	692	521	593	671	754
12g	ULCORED gnf.wks, coal, MDEA sep.	Greenfield	552	603	661	723	563	619	683	752	584	652	728	808
12b	ULCORED wks, coal, MDEA sep. (BAT)	Existing site modification	471	519	572	631	482	535	595	659	502	567	639	715
12.v	ULCORED wks, coal, VPSA sep.	Existing site modification	458	504	556	613	466	516	573	635	481	541	607	677
12g.v	ULCORED gnf.wks, coal, VPSA sep.	Greenfield	521	566	618	674	528	578	634	694	544	602	666	735
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	Existing site modification	443	485	533	585	450	496	548	604	464	518	578	642
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	Existing site modification	483	530	582	638	493	546	605	667	514	579	650	724
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	Greenfield	533	580	632	687	544	596	654	716	565	629	699	772
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	Existing site modification	467	511	560	612	477	526	580	638	496	556	621	690
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	Existing site modification	456	496	542	591	463	507	557	610	477	529	587	648
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	Greenfield	507	547	591	639	513	557	606	657	527	578	634	693
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	Existing site modification	441	479	521	566	448	489	534	583	460	508	561	617
13	ULCORED wks, exs coal syng., MDEA sep.	Existing site modification	559	617	682	753	571	635	707	785	595	673	759	850
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	Greenfield	623	679	744	814	634	697	768	844	656	732	815	904
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	Existing site modification	543	596	656	722	554	613	680	752	576	647	726	811
13.v	ULCORED wks, exs coal syng., VPSA sep.	Existing site modification	515	568	624	688	524	580	643	712	541	608	681	759
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	Greenfield	576	627	685	747	585	641	704	771	604	669	742	820
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	Existing site modification	497	544	597	655	506	558	616	679	523	584	652	725
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	Existing site modification	553	605	662	723	564	622	685	753	586	656	732	813
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	Greenfield	607	659	715	776	618	676	738	806	640	710	785	864
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	Existing site modification	538	586	639	697	548	601	661	724	568	633	703	778
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	Existing site modification	500	544	592	645	507	556	609	666	523	580	642	708
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	Greenfield	564	607	656	708	572	620	673	730	588	645	707	773
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	Existing site modification	486	528	574	624	494	540	591	645	509	564	624	687
14	ULCORED wks, bio., MDEA sep.	Existing site modification	554	589	630	676	548	579	617	659	535	559	589	624
14g	ULCORED gnf.wks, bio., MDEA sep.	Greenfield	620	655	695	740	613	643	679	719	597	618	645	677
14b	ULCORED wks, bio., MDEA sep. (BAT)	Existing site modification	538	569	606	646	531	557	589	626	516	534	557	585
14.v	ULCORED wks, bio., VPSA sep.	Existing site modification	527	557	592	631	517	542	571	605	498	511	530	552
14g.v	ULCORED gnf.wks, bio., VPSA sep.	Greenfield	593	623	658	697	583	607	637	670	563	576	594	616
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	Existing site modification	514	541	572	607	504	525	550	580	483	493	506	524
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	Existing site modification	550	580	615	654	542	569	600	634	528	546	569	595
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	Greenfield	601	632	666	704	594	620	650	683	578	595	617	642
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	Existing site modification	534	562	593	627	526	549	576	605	510	523	541	561
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	Existing site modification	527	552	582	614	517	538	560	586	496	504	516	530
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	Greenfield	579	604	632	663	568	586	609	633	545	552	562	574
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	Existing site modification	513	535	561	589	502	518	537	559	480	483	490	500
15	ULCORED wks, exs bio.syng., MDEA sep.	Existing site modification	696	717	743	773	669	675	685	700	615	590	569	553
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	Greenfield	768	790	816	847	740	745	756	771	683	657	636	620
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	Existing site modification	685	703	726	752	658	660	667	678	603	574	549	529
15.v	ULCORED wks, exs bio.syng., VPSA sep.	Existing site modification	666	684	706	733	638	639	646	656	581	551	525	503
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	Greenfield	725	741	762	786	696	696	700	708	637	605	577	552
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	Existing site modification	646	659	676	696	617	614	615	619	560	524	492	464
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	Existing site modification	696	712	732	755	668	669	673	681	614	583	557	533
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	Greenfield	752	768	788	810	724	724	728	734	667	635	607	582
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	Existing site modification	680	693	709	728	652	649	649	651	596	560	528	498
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	Existing site modification	652	663	678	694	623	618	615	615	565	526	490	457
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	Greenfield	717	728	742	758	687	681	679	678	627	588	552	518
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	Existing site modification	637	645	657	671	608	600	594	591	549	508	469	433
16	ULCOWIN wks, imp.elec.	Existing site modification	617	668	725	785	621	674	733	795	628	686	749	816
16g	ULCOWIN gnf.wks, imp.elec.	Greenfield	659	710	766	825	663	715	773	834	670	726	787	851
16b	ULCOWIN wks, imp.elec. (BAT)	Existing site modification	601	649	701	758	604	653	707	765	609	662	720	781

Table A-34: Production cost with emissions trading price for UK iron and steel sector sites

ID	Description	Project	2010-2050 trading price, 0-50£/tCO$_2$				2010-2050 trading price, 0-100£/tCO$_2$				2010-2050 trading price, 0-200£/tCO$_2$			
			Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050	Production cost 2020	Production cost 2030	Production cost 2040	Production cost 2050
			£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs	£/tcs
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	Existing site modification	504	569	641	717	542	628	722	819	617	747	883	1,024
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	Existing site modification	491	550	614	681	525	603	686	773	592	708	830	955
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	Existing site modification	477	537	602	672	508	585	667	754	568	680	797	919
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	Existing site modification	469	523	581	644	496	565	639	717	550	650	755	864
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	Existing site modification	480	540	606	676	514	595	680	770	584	704	829	959
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	Existing site modification	469	523	581	644	500	571	648	728	561	669	780	896
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	Existing site modification	458	514	575	640	486	558	635	716	542	646	755	868
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	Existing site modification	450	500	554	612	475	539	607	679	524	616	713	813
6.2	TGR-BF [V4] wks, MDEA sep.	Existing site modification	488	544	606	673	509	577	651	730	551	643	742	845
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	Existing site modification	475	524	578	637	492	551	615	683	526	605	689	777
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	Existing site modification	465	517	575	637	482	544	613	685	517	600	688	780
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	Existing site modification	456	503	554	610	470	525	585	648	499	570	646	725
6.2.v	TGR-BF [V4] wks, VPSA sep.	Existing site modification	463	514	571	631	481	543	610	681	518	600	688	780
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	Existing site modification	452	497	546	599	467	520	577	638	496	565	639	717
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	Existing site modification	446	494	548	605	461	518	580	647	492	566	646	730
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	Existing site modification	437	480	527	577	449	499	552	610	473	536	604	675
7	Hlsarna wks	Existing site modification	598	622	650	679	601	628	658	690	609	641	675	711
7b	Hlsarna wks (BAT)	Existing site modification	594	617	641	668	597	621	647	676	603	630	660	691
7s	Hlsarna wks, max scrap	Existing site modification	543	570	600	633	547	576	608	642	554	587	623	661
7bs	Hlsarna wks, max scrap (BAT)	Existing site modification	541	565	593	623	543	569	598	629	548	577	609	643
8	Hlsarna wks, MDEA sep.	Existing site modification	635	648	664	682	613	613	616	622	569	544	522	502
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	632	642	655	669	608	605	605	606	562	533	506	481
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	575	593	614	638	558	567	578	593	525	515	508	503
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	572	587	606	626	554	560	568	579	519	504	492	483
8.v	Hlsarna wks, VPSA sep.	Existing site modification	624	636	652	670	602	602	606	612	559	535	513	494
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	620	630	643	658	597	594	594	596	552	523	497	472
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	566	584	605	629	550	558	570	584	517	507	500	496
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	563	578	597	617	545	551	560	570	511	497	485	476
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	Existing site modification	504	569	641	717	542	628	722	819	617	747	883	1,024
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	Existing site modification	491	550	614	681	525	603	686	773	592	708	830	955
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	Existing site modification	477	537	602	672	508	585	667	754	568	680	797	919
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	Existing site modification	469	523	581	644	496	565	639	717	550	650	755	864
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	Existing site modification	480	540	606	676	514	595	680	770	584	704	829	959
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	Existing site modification	469	523	581	644	500	571	648	728	561	669	780	896
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	Existing site modification	458	514	575	640	486	558	635	716	542	646	755	868
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	Existing site modification	450	500	554	612	475	539	607	679	524	616	713	813
8	Hlsarna wks, MDEA sep.	Existing site modification	661	688	719	751	665	694	726	761	672	705	742	781
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	657	682	709	739	660	686	715	746	665	694	725	759
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	595	624	657	692	598	629	664	701	605	640	678	719
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	592	619	648	680	594	622	653	687	599	629	663	699
8.v	Hlsarna wks, VPSA sep.	Existing site modification	649	677	707	740	653	683	716	751	661	696	733	773
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	646	670	698	728	648	675	704	735	654	684	716	751
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	586	615	647	683	589	621	655	692	597	632	671	712
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	583	609	639	671	585	614	645	678	590	622	656	692
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	Existing site modification	493	552	617	688	520	594	675	760	573	678	789	905
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	Existing site modification	480	533	590	652	503	568	639	713	548	639	736	836
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	Existing site modification	469	524	584	649	491	558	631	708	534	626	724	827
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	Existing site modification	460	509	563	621	479	538	603	671	516	596	682	772
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	Existing site modification	469	523	582	646	492	560	633	711	540	635	735	840
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	Existing site modification	458	506	558	614	478	537	601	668	518	600	686	777
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	Existing site modification	450	501	557	617	469	531	598	670	508	593	682	776
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	Existing site modification	441	486	536	589	458	512	571	633	490	563	640	721
8	Hlsarna wks, MDEA sep.	Existing site modification	644	661	682	705	630	640	653	668	604	598	595	595
8b	Hlsarna wks, MDEA sep. (BAT)	Existing site modification	640	655	673	693	626	632	642	653	596	586	579	574
8s	Hlsarna wks, max scrap, MDEA sep.	Existing site modification	582	603	628	656	572	588	607	629	552	557	564	575
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	Existing site modification	578	598	620	644	567	580	596	615	546	546	549	555
8.v	Hlsarna wks, VPSA sep.	Existing site modification	632	650	671	693	619	629	642	658	593	588	586	587
8b.v	Hlsarna wks, VPSA sep. (BAT)	Existing site modification	629	644	661	681	614	621	631	642	586	576	570	565
8s.v	Hlsarna wks, max scrap, VPSA sep.	Existing site modification	572	594	619	647	563	579	598	620	544	549	557	568
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	Existing site modification	569	589	611	635	559	572	588	606	537	538	542	548

Table A-35: Production cost with emissions trading price for UK iron and steel sector sites with alternative configuration

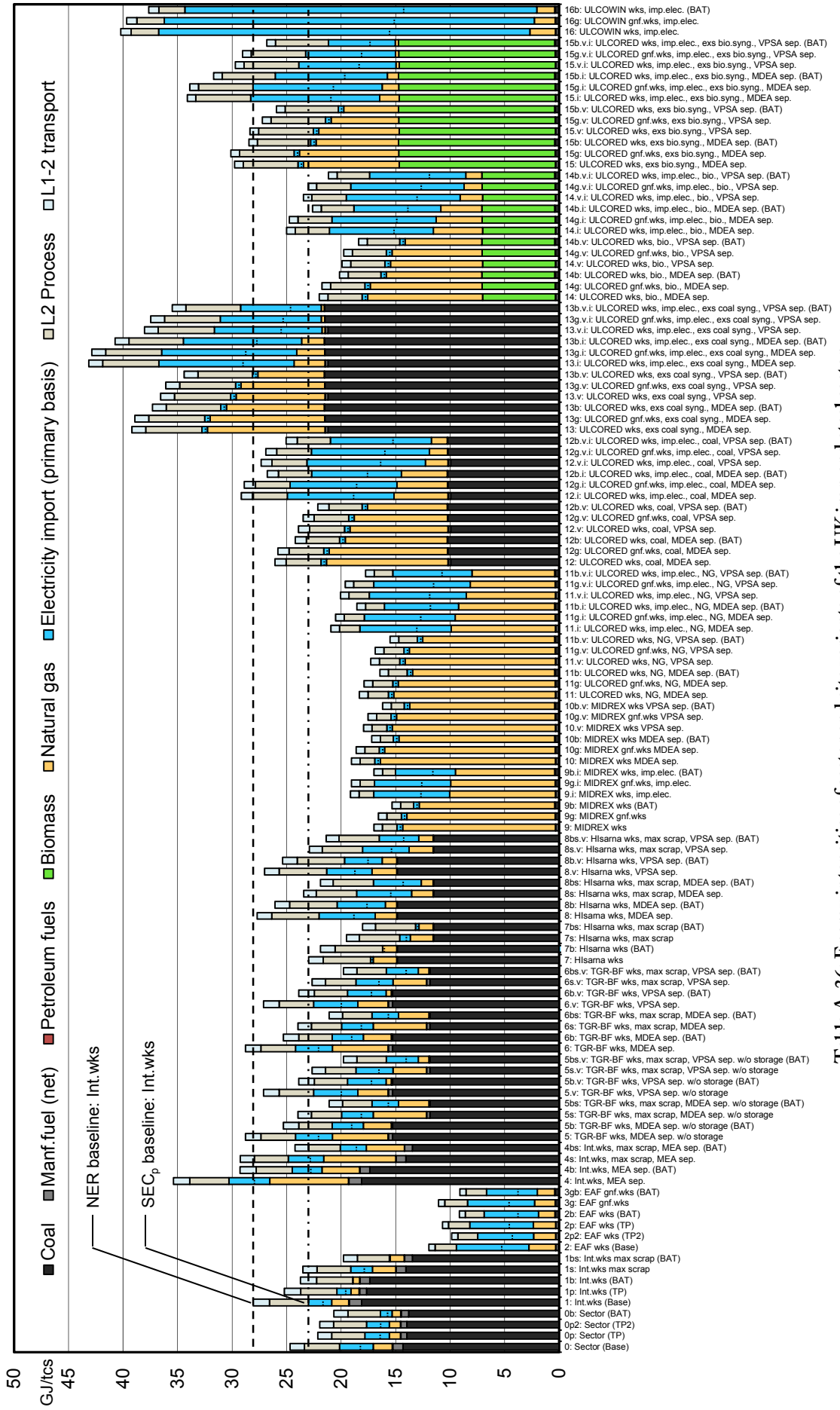

Table A-36: Energy intensities of sector and site variants of the UK iron and steel sector

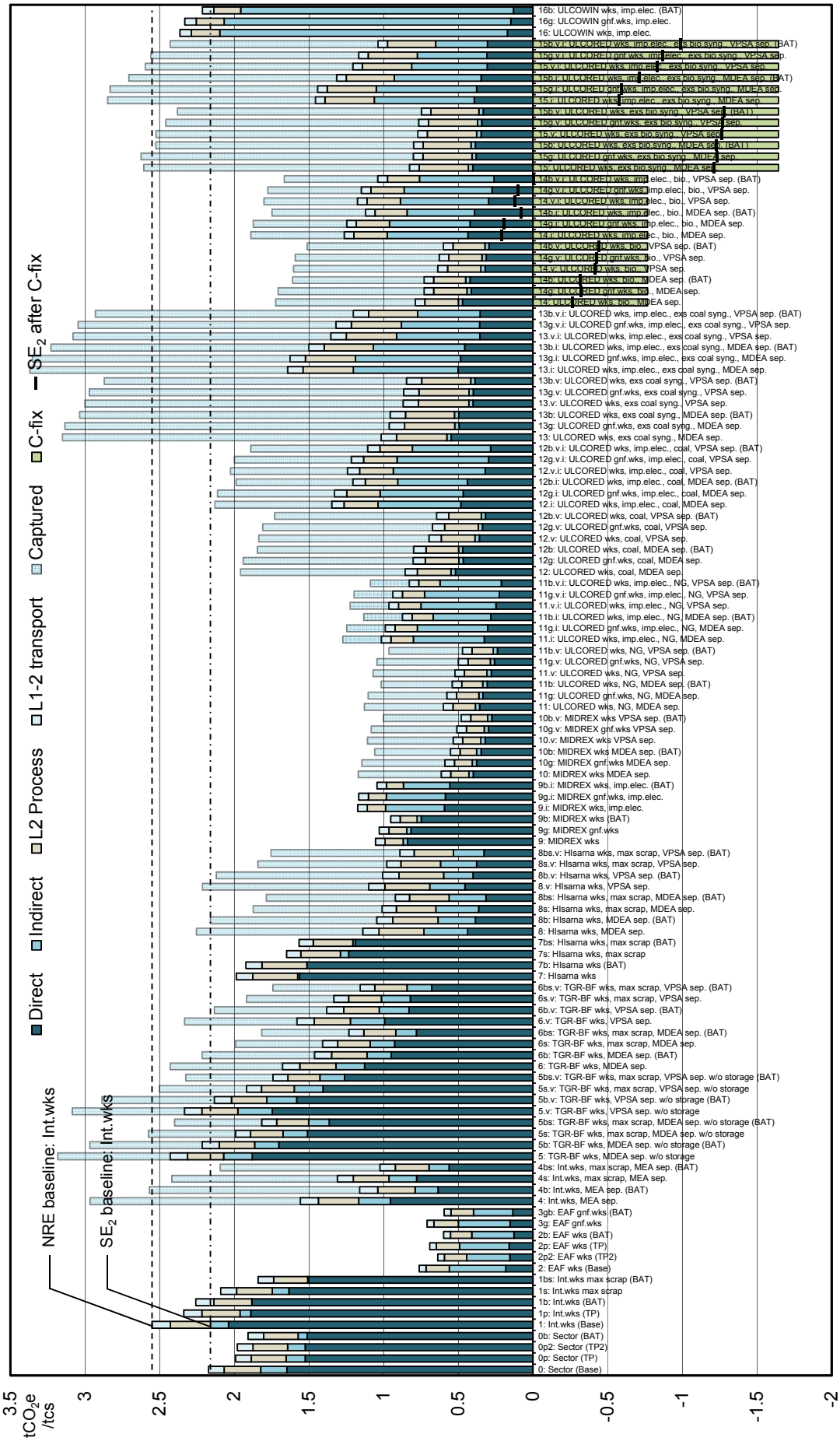

Table A-37: GhG emission intensities of sector and site variants of the UK iron and steel sector

ID	Description	Coal	Natural gas	Petroleum fuels	Manf.fuel (net)	Biomass	Electricity import	Electricity import (primary basis)	SEC	SECp	L2 Process	L1-2 transport	NER
		GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs
0	Sector (Base)	14.32	1.76	0.03	0.95		1.16	3.08	18.23	20.14	3.23	1.30	24.67
0p	Sector (TP)	13.98	1.03	0.03	0.54		0.85	2.25	16.43	17.82	3.04	1.28	22.15
0p2	Sector (TP2)	13.98	1.03	0.03	0.54		0.79	2.10	16.37	17.67	3.01	1.28	21.96
0b	Sector (BAT)	13.80	0.80	0.03	0.70		0.41	1.07	15.74	16.41	2.97	1.28	20.66
1	Int.wks (Base)	18.11	1.58	0.04	1.14		0.80	2.13	21.67	23.00	3.57	1.50	28.07
1p	Int.wks (TP)	17.68	0.76	0.04	0.63		0.49	1.29	19.58	20.39	3.33	1.48	25.19
1b	Int.wks (BAT)	17.38	0.61	0.04	0.89		0.01	0.03	18.93	18.95	3.31	1.48	23.73
1s	Int.wks max scrap	14.05	2.14	0.04	0.91		0.75	1.98	17.88	19.11	3.09	1.29	23.50
1bs	Int.wks max scrap (BAT)	13.48	1.26	0.04	0.70		0.04	0.09	15.52	15.57	2.93	1.28	19.78
2	EAF wks (Base)	0.09	2.45	0.02	0.21		2.52	6.65	5.29	9.42	1.96	0.56	11.94
2p2	EAF wks (TP2)	0.09	2.03	0.02	0.21		1.94	5.12	4.29	7.48	1.81	0.56	9.85
2p	EAF wks (TP)	0.09	2.04	0.02	0.21		2.21	5.85	4.57	8.22	1.95	0.55	10.71
2b	EAF wks (BAT)	0.37	1.50	0.02			1.89	4.99	3.78	6.88	1.72	0.56	9.16
3g	EAF gnf.wks	0.35	1.88	0.04			2.32	6.14	4.58	8.40	2.10	0.56	11.06
3gb	EAF gnf.wks (BAT)	0.37	1.61	0.04			1.76	4.65	3.78	6.66	1.88	0.56	9.10
4	Int.wks, MEA sep.	18.11	7.21	0.04	1.18		1.42	3.76	27.96	30.30	3.57	1.50	35.37
4b	Int.wks, MEA sep. (BAT)	17.38	3.44	0.04	0.89		1.03	2.73	22.78	24.48	3.31	1.48	29.26
4s	Int.wks, max scrap, MEA sep.	14.05	6.59	0.04	0.91		1.23	3.26	22.82	24.85	3.09	1.30	29.24
4bs	Int.wks, max scrap, MEA sep. (BAT)	13.48	3.49	0.04	0.69		0.90	2.38	18.60	20.07	2.89	1.28	24.24
5	TGR-BF wks, MDEA sep. w/o storage	15.28	5.10	0.04	0.38		1.28	3.39	22.08	24.19	3.17	1.42	28.78
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)	15.28	2.55	0.04	0.09		1.09	2.87	19.04	20.83	3.06	1.41	25.30
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage	11.85	4.88	0.04	0.30		1.09	2.89	18.16	19.95	2.78	1.23	23.97
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)	11.85	2.79	0.04	0.07		0.91	2.42	15.66	17.17	2.70	1.23	21.09
5.v	TGR-BF wks, VPSA sep. w/o storage	15.28	2.76	0.04	0.38		1.54	4.06	19.99	22.52	3.17	1.42	27.11
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)	15.28	0.47	0.04	0.09		1.34	3.54	17.21	19.41	3.06	1.41	23.88
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage	11.85	3.05	0.04	0.30		1.29	3.41	16.53	18.65	2.78	1.23	22.66
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)	11.85	0.97	0.04	0.07		1.11	2.94	14.04	15.86	2.70	1.23	19.79
6	TGR-BF wks, MDEA sep.	15.28	5.10	0.04	0.38		1.28	3.39	22.08	24.19	3.17	1.42	28.78
6b	TGR-BF wks, MDEA sep. (BAT)	15.28	2.55	0.04	0.09		1.09	2.87	19.04	20.83	3.06	1.41	25.30
6s	TGR-BF wks, max scrap, MDEA sep.	11.85	4.88	0.04	0.30		1.09	2.89	18.16	19.95	2.78	1.23	23.97
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)	11.85	2.79	0.04	0.07		0.91	2.42	15.66	17.17	2.70	1.23	21.09
6.v	TGR-BF wks, VPSA sep.	15.28	2.76	0.04	0.38		1.54	4.06	19.99	22.52	3.17	1.42	27.11
6b.v	TGR-BF wks, VPSA sep. (BAT)	15.28	0.47	0.04	0.09		1.34	3.54	17.21	19.41	3.06	1.41	23.88
6s.v	TGR-BF wks, max scrap, VPSA sep.	11.85	3.05	0.04	0.30		1.29	3.41	16.53	18.65	2.78	1.23	22.66
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)	11.85	0.97	0.04	0.07		1.11	2.94	14.04	15.86	2.70	1.23	19.79
7	Hlsarna wks	14.86	2.16	0.04			0.09	0.25	17.15	17.30	4.35	1.34	22.99
7b	Hlsarna wks (BAT)	14.86	1.31	0.04			-0.18	-0.48	16.02	15.73	4.34	1.34	21.41
7s	Hlsarna wks, max scrap	11.53	2.09	0.04			0.37	0.98	14.02	14.63	3.70	1.17	19.50
7bs	Hlsarna wks, max scrap (BAT)	11.53	1.29	0.04			0.12	0.31	12.97	13.16	3.69	1.17	18.03
8	Hlsarna wks, MDEA sep.	14.86	1.97	0.04			1.95	5.15	18.82	22.02	4.35	1.34	27.70
8b	Hlsarna wks, MDEA sep. (BAT)	14.86	1.05	0.04			1.68	4.43	17.62	20.38	4.35	1.34	26.06
8s	Hlsarna wks, max scrap, MDEA sep.	11.53	1.97	0.04			1.91	5.05	15.44	18.58	3.70	1.17	23.44
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	11.53	1.10	0.04			1.66	4.38	14.32	17.04	3.69	1.17	21.90
8.v	Hlsarna wks, VPSA sep.	14.86	2.26	0.04			1.58	4.17	18.74	21.33	4.35	1.34	27.01
8b.v	Hlsarna wks, VPSA sep. (BAT)	14.86	1.34	0.04			1.30	3.44	17.54	19.68	4.34	1.34	25.36
8s.v	Hlsarna wks, max scrap, VPSA sep.	11.53	2.20	0.04			1.62	4.28	15.38	18.04	3.70	1.17	22.90
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	11.53	1.33	0.04			1.37	3.61	14.26	16.50	3.69	1.17	21.36
9	MIDREX wks	0.09	14.02	0.04	0.21		0.19	0.51	14.55	14.87	1.34	0.79	17.00
9g	MIDREX gnf.wks	0.35	13.59	0.04			0.19	0.51	14.16	14.48	1.32	0.79	16.59
9b	MIDREX wks (BAT)	0.37	12.43	0.04			0.19	0.51	13.04	13.35	1.19	0.79	15.33
9.i	MIDREX wks, imp.elec.	0.09	9.70	0.04	0.21		2.64	6.97	12.68	17.01	1.34	0.79	19.14
9g.i	MIDREX gnf.wks, imp.elec.	0.35	9.57	0.04			2.64	6.99	12.60	16.95	1.32	0.79	19.06
9b.i	MIDREX wks, imp.elec. (BAT)	0.37	9.11	0.04			2.08	5.49	11.59	15.00	1.19	0.79	16.98
10	MIDREX wks MDEA sep.	0.09	16.07	0.04	0.21		0.19	0.51	16.60	16.91	1.34	0.79	19.04
10g	MIDREX gnf.wks MDEA sep.	0.35	15.63	0.04			0.19	0.51	16.20	16.52	1.32	0.79	18.63
10b	MIDREX wks MDEA sep. (BAT)	0.37	14.29	0.04			0.19	0.51	14.89	15.21	1.19	0.79	17.19
10.v	MIDREX wks VPSA sep.	0.09	14.97	0.04	0.21		0.19	0.51	15.50	15.82	1.34	0.79	17.95
10g.v	MIDREX gnf.wks VPSA sep.	0.35	14.54	0.04			0.19	0.51	15.11	15.43	1.32	0.79	17.54
10b.v	MIDREX wks VPSA sep. (BAT)	0.37	13.30	0.04			0.19	0.51	13.90	14.21	1.19	0.79	16.19
11	ULCORED wks, NG, MDEA sep.	0.09	14.82	0.04	0.21		0.19	0.51	15.36	15.67	1.86	0.79	18.32
11g	ULCORED gnf.wks, NG, MDEA sep.	0.35	14.38	0.04			0.19	0.51	14.96	15.27	1.84	0.79	17.90
11b	ULCORED wks, NG, MDEA sep. (BAT)	0.37	13.04	0.04			0.19	0.51	13.64	13.95	1.71	0.79	16.45
11.v	ULCORED wks, NG, VPSA sep.	0.09	13.79	0.04	0.21		0.19	0.51	14.32	14.63	1.86	0.79	17.28
11g.v	ULCORED gnf.wks, NG, VPSA sep.	0.35	13.35	0.04			0.19	0.51	13.92	14.24	1.84	0.79	16.87
11b.v	ULCORED wks, NG, VPSA sep. (BAT)	0.37	12.11	0.04			0.19	0.51	12.71	13.02	1.71	0.79	15.52
11.i	ULCORED wks, imp.elec., NG, MDEA sep.	0.09	9.56	0.04	0.21		3.17	8.38	13.07	18.28	1.86	0.79	20.93
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.	0.35	9.16	0.04			3.15	8.33	12.69	17.87	1.84	0.79	20.50
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)	0.37	8.83	0.04			2.58	6.81	11.81	16.05	1.71	0.79	18.54
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.	0.09	8.18	0.04	0.21		3.36	8.89	11.89	17.41	1.86	0.79	20.06
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.	0.35	7.78	0.04			3.34	8.84	11.51	17.00	1.84	0.79	19.63
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)	0.37	7.58	0.04			2.75	7.27	10.74	15.27	1.71	0.79	17.76
12	ULCORED wks, coal, MDEA sep.	9.94	11.15	0.04	0.21		0.19	0.51	21.54	21.85	3.20	1.01	26.06
12g	ULCORED gnf.wks, coal, MDEA sep.	10.20	10.85	0.04			0.19	0.51	21.28	21.60	3.18	1.01	25.79
12b	ULCORED wks, coal, MDEA sep. (BAT)	10.23	9.37	0.04			0.19	0.51	19.82	20.14	3.05	1.01	24.20
12.v	ULCORED wks, coal, VPSA sep.	9.94	8.99	0.04	0.21		0.19	0.51	19.38	19.69	3.20	1.01	23.90
12g.v	ULCORED gnf.wks, coal, VPSA sep.	10.20	8.56	0.04			0.19	0.51	18.99	19.30	3.18	1.01	23.49
12b.v	ULCORED wks, coal, VPSA sep. (BAT)	10.23	7.31	0.04			0.19	0.51	17.77	18.08	3.05	1.01	22.14
12.i	ULCORED wks, imp.elec., coal, MDEA sep.	9.94	4.94	0.04	0.21		3.71	9.80	18.84	24.94	3.20	1.01	29.15
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.	10.20	4.64	0.04			3.71	9.81	18.58	24.69	3.18	1.01	28.88
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)	10.23	4.20	0.04			3.11	8.23	17.58	22.70	3.05	1.01	26.76
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.	9.94	2.07	0.04	0.21		4.11	10.87	16.37	23.13	3.20	1.01	27.34
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.	10.20	1.66	0.04			4.09	10.82	15.99	22.72	3.18	1.01	26.91
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)	10.23	1.47	0.04			3.50	9.25	15.23	20.98	3.05	1.01	25.04
13	ULCORED wks, exs coal syng., MDEA sep.	21.22	10.79	0.04	0.21		0.19	0.51	32.45	32.76	5.15	1.26	39.18
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.	21.48	10.50	0.04			0.19	0.51	32.20	32.52	5.13	1.27	38.91
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)	21.50	8.98	0.04			0.19	0.51	30.71	31.03	5.00	1.27	37.29
13.v	ULCORED wks, exs coal syng., VPSA sep.	21.22	8.15	0.04	0.21		0.19	0.51	29.82	30.13	5.15	1.26	36.54
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.	21.48	7.66	0.04			0.19	0.51	29.36	29.68	5.13	1.27	36.07
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)	21.50	6.09	0.04			0.19	0.51	27.82	28.13	5.00	1.27	34.39
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.	21.22	2.84	0.04	0.21		4.69	12.40	29.00	36.71	5.15	1.26	43.13
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.	21.48	2.54	0.04			4.69	12.41	28.75	36.47	5.13	1.27	42.86
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)	21.50	2.08	0.04			4.10	10.83	27.72	34.45	5.00	1.27	40.72
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.	21.22	0.29	0.04	0.21		3.73	9.86	25.49	31.62	5.15	1.26	38.04
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.	21.48	0.30	0.04			3.50	9.26	25.32	31.07	5.13	1.27	37.47
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)	21.50	0.29	0.04			2.80	7.40	24.63	29.23	5.00	1.27	35.49
14	ULCORED wks, bio., MDEA sep.	0.09	10.54	0.04	0.21	6.68	0.19	0.51	17.76	18.07	3.14	0.79	22.00
14g	ULCORED gnf.wks, bio., MDEA sep.	0.35	10.27	0.04		6.68	0.19	0.51	17.52	17.84	3.12	0.79	21.74
14b	ULCORED wks, bio., MDEA sep. (BAT)	0.37	8.76	0.04		6.68	0.19	0.51	16.04	16.35	2.99	0.79	20.13
14.v	ULCORED wks, bio., VPSA sep.	0.09	8.45	0.04	0.21	6.68	0.19	0.51	15.67	15.98	3.14	0.79	19.91
14g.v	ULCORED gnf.wks, bio., VPSA sep.	0.35	8.27	0.04		6.68	0.19	0.51	15.53	15.84	3.12	0.79	19.75
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	0.37	7.03	0.04		6.68	0.19	0.51	14.31	14.62	2.99	0.79	18.40
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	0.09	4.51	0.04	0.21	6.68	3.61	9.54	15.14	21.07	3.14	0.79	25.00
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	0.35	4.22	0.04		6.68	3.61	9.56	14.90	20.84	3.12	0.79	24.75
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	0.37	3.77	0.04		6.68	3.01	7.97	13.88	18.83	2.99	0.79	22.61
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	0.09	2.07	0.04	0.21	6.68	3.95	10.45	13.04	19.54	3.14	0.79	23.46
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	0.35	1.66	0.04		6.68	3.93	10.40	12.66	19.13	3.12	0.79	23.03
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	0.37	1.47	0.04		6.68	3.34	8.83	11.90	17.39	2.99	0.79	21.16
15	ULCORED wks, exs bio.syng., MDEA sep.	0.09	8.78	0.04	0.21	14.33	0.19	0.51	23.64	23.95	5.02	0.79	29.76
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	0.35	9.10	0.04		14.33	0.19	0.51	24.00	24.32	5.00	0.79	30.10
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	0.37	7.56	0.04		14.33	0.19	0.51	22.49	22.80	4.87	0.79	28.46
15.v	ULCORED wks, exs bio.syng., VPSA sep.	0.09	7.37	0.04	0.21	14.33	0.19	0.51	22.23	22.54	5.02	0.79	28.35
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	0.35	6.22	0.04		14.33	0.19	0.51	21.12	21.43	5.00	0.79	27.22
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	0.37	5.03	0.04		14.33	0.19	0.51	19.95	20.27	4.87	0.79	25.92
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	0.09	1.80	0.04	0.21	14.33	4.48	11.84	20.94	28.30	5.02	0.79	34.11
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	0.35	1.52	0.04		14.33	4.48	11.86	20.71	28.09	5.00	0.79	33.87
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	0.37	1.04	0.04		14.33	3.88	10.27	19.66	26.04	4.87	0.79	31.70
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	0.09	0.30	0.04	0.21	14.33	3.37	8.92	18.34	23.89	5.02	0.79	29.69
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	0.35	0.30	0.04		14.33	3.12	8.24	18.13	23.25	5.00	0.79	29.04
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	0.37	0.30	0.04		14.33	2.32	6.13	17.35	21.16	4.87	0.79	26.82
16	ULCOWIN wks, imp.elec.	0.09	2.34	0.04	0.21		12.88	34.05	15.56	36.73	2.52	0.94	40.20
16g	ULCOWIN gnf.wks, imp.elec.	0.35	1.90	0.04			12.83	33.93	15.12	36.22	2.50	0.94	39.67
16b	ULCOWIN wks, imp.elec. (BAT)	0.37	1.63	0.04			12.21	32.29	14.26	34.34	2.37	0.94	37.65

Table A-38: Energy splits of technology sites constructed for the UK iron and steel sector

ID	Description	Coal	Natural gas	Petroleum fuels	Manf.fuel (net)	Biomass	Electricity import	Electricity import (primary basis)	SEC	SECp	L2 Process	L1-2 transport	NER
		GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs	GJ/tcs
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage	13.40	5.26	0.04	0.52		1.28	3.25	20.50	22.46	2.77	1.38	26.61
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)	13.40	2.60	0.04	0.22		1.15	2.92	17.42	19.19	2.66	1.37	23.22
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage	10.40	4.98	0.04	0.40		1.09	2.76	16.91	18.58	2.42	1.20	22.20
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)	10.40	2.76	0.04	0.17		0.98	2.50	14.35	15.86	2.33	1.19	19.38
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage	13.40	2.91	0.04	0.52		1.53	3.89	18.41	20.76	2.77	1.38	24.91
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)	13.40	0.47	0.04	0.22		1.41	3.57	15.54	17.70	2.66	1.37	21.72
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage	10.40	3.16	0.04	0.40		1.29	3.26	15.28	17.26	2.42	1.20	20.87
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)	10.40	0.94	0.04	0.17		1.18	2.99	12.72	14.53	2.33	1.19	18.06
6.2	TGR-BF [V4] wks, MDEA sep.	13.40	5.26	0.04	0.52		1.28	3.25	20.50	22.46	2.77	1.38	26.61
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)	13.40	2.60	0.04	0.22		1.15	2.92	17.42	19.19	2.66	1.37	23.22
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.	10.40	4.98	0.04	0.40		1.09	2.76	16.91	18.58	2.42	1.20	22.20
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)	10.40	2.76	0.04	0.17		0.98	2.50	14.35	15.86	2.33	1.19	19.38
6.2.v	TGR-BF [V4] wks, VPSA sep.	13.40	2.91	0.04	0.52		1.53	3.89	18.41	20.76	2.77	1.38	24.91
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)	13.40	0.47	0.04	0.22		1.41	3.57	15.54	17.70	2.66	1.37	21.72
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.	10.40	3.16	0.04	0.40		1.29	3.26	15.28	17.26	2.42	1.20	20.87
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)	10.40	0.94	0.04	0.17		1.18	2.99	12.72	14.53	2.33	1.19	18.06
7	Hlsarna wks	0.42	2.16	0.04		15.17	0.09	0.25	17.87	18.03	3.23	1.01	22.26
7b	Hlsarna wks (BAT)	0.42	1.31	0.04		15.17	-0.18	-0.48	16.75	16.45	3.22	1.01	20.68
7s	Hlsarna wks, max scrap	0.32	2.09	0.04		11.76	0.37	0.98	14.58	15.19	2.83	0.92	18.94
7bs	Hlsarna wks, max scrap (BAT)	0.32	1.29	0.04		11.76	0.12	0.31	13.53	13.72	2.83	0.92	17.47
8	Hlsarna wks, MDEA sep.	0.42	1.95	0.04		15.17	2.03	5.36	19.60	22.93	3.23	1.01	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	0.42	1.03	0.04		15.17	1.75	4.64	18.40	21.29	3.23	1.01	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	0.32	1.95	0.04		11.76	1.97	5.21	16.05	19.28	2.83	0.92	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	0.32	1.09	0.04		11.76	1.72	4.54	14.93	17.75	2.83	0.92	21.49
8.v	Hlsarna wks, VPSA sep.	0.42	2.26	0.04		15.17	1.63	4.31	19.52	22.20	3.23	1.01	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	0.42	1.34	0.04		15.17	1.36	3.59	18.32	20.55	3.22	1.01	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	0.32	2.20	0.04		11.76	1.66	4.40	15.98	18.71	2.83	0.92	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	0.32	1.33	0.04		11.76	1.41	3.73	14.86	17.18	2.83	0.92	20.92
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]	13.40	5.26	0.04	0.52		1.28	3.25	20.50	22.46	2.77	1.38	26.61
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)	13.40	2.60	0.04	0.22		1.15	2.92	17.42	19.19	2.66	1.37	23.22
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]	10.40	4.98	0.04	0.40		1.09	2.76	16.91	18.58	2.42	1.20	22.20
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)	10.40	2.76	0.04	0.17		0.98	2.50	14.35	15.86	2.33	1.19	19.38
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]	13.40	2.91	0.04	0.52		1.53	3.89	18.41	20.76	2.77	1.38	24.91
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)	13.40	0.47	0.04	0.22		1.41	3.57	15.54	17.70	2.66	1.37	21.72
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]	10.40	3.16	0.04	0.40		1.29	3.26	15.28	17.26	2.42	1.20	20.87
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)	10.40	0.94	0.04	0.17		1.18	2.99	12.72	14.53	2.33	1.19	18.06
8	Hlsarna wks, MDEA sep.	0.42	1.95	0.04		15.17	2.03	5.36	19.60	22.93	3.23	1.01	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	0.42	1.03	0.04		15.17	1.75	4.64	18.40	21.29	3.23	1.01	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	0.32	1.95	0.04		11.76	1.97	5.21	16.05	19.28	2.83	0.92	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	0.32	1.09	0.04		11.76	1.72	4.54	14.93	17.75	2.83	0.92	21.49
8.v	Hlsarna wks, VPSA sep.	0.42	2.26	0.04		15.17	1.63	4.31	19.52	22.20	3.23	1.01	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	0.42	1.34	0.04		15.17	1.36	3.59	18.32	20.55	3.22	1.01	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	0.32	2.20	0.04		11.76	1.66	4.40	15.98	18.71	2.83	0.92	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	0.32	1.33	0.04		11.76	1.41	3.73	14.86	17.18	2.83	0.92	20.92
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]	13.40	5.26	0.04	0.52		1.28	3.25	20.50	22.46	2.77	1.38	26.61
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)	13.40	2.60	0.04	0.22		1.15	2.92	17.42	19.19	2.66	1.37	23.22
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]	10.40	4.98	0.04	0.40		1.09	2.76	16.91	18.58	2.42	1.20	22.20
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)	10.40	2.76	0.04	0.17		0.98	2.50	14.35	15.86	2.33	1.19	19.38
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]	13.40	2.91	0.04	0.52		1.53	3.89	18.41	20.76	2.77	1.38	24.91
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)	13.40	0.47	0.04	0.22		1.41	3.57	15.54	17.70	2.66	1.37	21.72
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]	10.40	3.16	0.04	0.40		1.29	3.26	15.28	17.26	2.42	1.20	20.87
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)	10.40	0.94	0.04	0.17		1.18	2.99	12.72	14.53	2.33	1.19	18.06
8	Hlsarna wks, MDEA sep.	0.42	1.95	0.04		15.17	2.03	5.36	19.60	22.93	3.23	1.01	27.17
8b	Hlsarna wks, MDEA sep. (BAT)	0.42	1.03	0.04		15.17	1.75	4.64	18.40	21.29	3.23	1.01	25.53
8s	Hlsarna wks, max scrap, MDEA sep.	0.32	1.95	0.04		11.76	1.97	5.21	16.05	19.28	2.83	0.92	23.03
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	0.32	1.09	0.04		11.76	1.72	4.54	14.93	17.75	2.83	0.92	21.49
8.v	Hlsarna wks, VPSA sep.	0.42	2.26	0.04		15.17	1.63	4.31	19.52	22.20	3.23	1.01	26.44
8b.v	Hlsarna wks, VPSA sep. (BAT)	0.42	1.34	0.04		15.17	1.36	3.59	18.32	20.55	3.22	1.01	24.79
8s.v	Hlsarna wks, max scrap, VPSA sep.	0.32	2.20	0.04		11.76	1.66	4.40	15.98	18.71	2.83	0.92	22.46
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	0.32	1.33	0.04		11.76	1.41	3.73	14.86	17.18	2.83	0.92	20.92

Table A-39: Energy slits of technology sites with alternative configuration, constructed for the UK iron and steel sector

ID	Description	C-fix	Direct	Indirect	Captured	SE_1	SE_2	L2 Process	L1-2 transport	NRE
		$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$
0	Sector (Base)		1,650	174		1,650	1,824	245	106	2,174
0p	Sector (TP)		1,527	127		1,527	1,654	234	104	1,992
0p2	Sector (TP2)		1,525	119		1,525	1,644	233	104	1,981
0b	Sector (BAT)		1,513	60.79		1,513	1,574	231	104	1,909
1	Int.wks (Base)		2,040	120		2,040	2,160	268	122	2,551
1p	Int.wks (TP)		1,890	72.97		1,890	1,963	255	120	2,339
1b	Int.wks (BAT)		1,882	1.79		1,882	1,884	254	120	2,258
1s	Int.wks max scrap		1,635	112		1,635	1,747	239	105	2,091
1bs	Int.wks max scrap (BAT)		1,505	5.25		1,505	1,510	228	104	1,841
2	EAF wks (Base)		184	376		184	561	156	45.14	762
2p2	EAF wks (TP2)		156	290		156	446	148	45.14	639
2p	EAF wks (TP)		161	331		161	492	156	45.14	693
2b	EAF wks (BAT)		129	282		129	411	142	45.27	599
3g	EAF gnf.wks		154	347		154	501	164	45.33	710
3gb	EAF gnf.wks (BAT)		136	263		136	399	151	45.37	595
4	Int.wks, MEA sep.		956	213	1,408	956	1,169	268	122	1,559
4b	Int.wks, MEA sep. (BAT)		636	155	1,408	636	791	251	120	1,161
4s	Int.wks, max scrap, MEA sep.		781	184	1,109	781	965	239	105	1,310
4bs	Int.wks, max scrap, MEA sep. (BAT)		563	134	1,069	563	697	225	104	1,026
5	TGR-BF wks, MDEA sep. w/o storage		1,881	192	752	1,881	2,073	242	115	2,430
5b	TGR-BF wks, MDEA sep. w/o storage (BAT)		1,702	162	752	1,702	1,865	237	115	2,216
5s	TGR-BF wks, max scrap, MDEA sep. w/o storage		1,511	163	584	1,511	1,674	219	99.95	1,993
5bs	TGR-BF wks, max scrap, MDEA sep. w/o storage (BAT)		1,366	137	584	1,366	1,503	214	99.53	1,817
5.v	TGR-BF wks, VPSA sep. w/o storage		1,747	230	752	1,747	1,977	242	115	2,334
5b.v	TGR-BF wks, VPSA sep. w/o storage (BAT)		1,583	200	752	1,583	1,783	237	115	2,135
5s.v	TGR-BF wks, max scrap, VPSA sep. w/o storage		1,407	193	584	1,407	1,600	219	99.95	1,918
5bs.v	TGR-BF wks, max scrap, VPSA sep. w/o storage (BAT)		1,262	166	584	1,262	1,429	214	99.53	1,743
6	TGR-BF wks, MDEA sep.		1,128	192	752	1,128	1,320	242	115	1,677
6b	TGR-BF wks, MDEA sep. (BAT)		950	162	752	950	1,112	237	115	1,464
6s	TGR-BF wks, max scrap, MDEA sep.		928	163	584	928	1,091	219	99.95	1,409
6bs	TGR-BF wks, max scrap, MDEA sep. (BAT)		783	137	584	783	920	214	99.53	1,234
6.v	TGR-BF wks, VPSA sep.		994	230	752	994	1,224	242	115	1,581
6b.v	TGR-BF wks, VPSA sep. (BAT)		831	200	752	831	1,031	237	115	1,382
6s.v	TGR-BF wks, max scrap, VPSA sep.		823	193	584	823	1,016	219	99.95	1,335
6bs.v	TGR-BF wks, max scrap, VPSA sep. (BAT)		679	166	584	679	845	214	99.53	1,159
7	Hlsarna wks		1,563	14.16		1,563	1,577	301	109	1,987
7b	Hlsarna wks (BAT)		1,515			1,515	1,515	301	109	1,924
7s	Hlsarna wks, max scrap		1,236	55.60		1,236	1,291	264	94.86	1,651
7bs	Hlsarna wks, max scrap (BAT)		1,190	17.60		1,190	1,208	264	94.86	1,567
8	Hlsarna wks, MDEA sep.		439	292	1,113	439	731	301	109	1,141
8b	Hlsarna wks, MDEA sep. (BAT)		387	251	1,113	387	637	301	109	1,047
8s	Hlsarna wks, max scrap, MDEA sep.		365	286	863	365	651	264	94.86	1,010
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)		316	248	863	316	564	264	94.86	923
8.v	Hlsarna wks, VPSA sep.		456	236	1,113	456	692	301	109	1,102
8b.v	Hlsarna wks, VPSA sep. (BAT)		403	195	1,113	403	598	301	109	1,008
8s.v	Hlsarna wks, max scrap, VPSA sep.		379	242	863	379	621	264	94.86	980
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)		329	204	863	329	533	264	94.86	892
9	MIDREX wks		841	28.58		841	870	121	64.01	1,055
9g	MIDREX gnf.wks		818	28.58		818	846	120	64.09	1,030
9b	MIDREX wks (BAT)		749	28.58		749	778	112	64.14	954
9.i	MIDREX wks, imp.elec.		595	394		595	989	121	64.01	1,174
9g.i	MIDREX gnf.wks, imp.elec.		588	395		588	984	120	64.09	1,167
9b.i	MIDREX wks, imp.elec. (BAT)		559	311		559	869	112	64.14	1,046
10	MIDREX wks MDEA sep.		401	28.58	557	401	430	121	64.01	615
10g	MIDREX gnf.wks MDEA sep.		379	28.58	555	379	407	120	64.09	591
10b	MIDREX wks MDEA sep. (BAT)		349	28.58	507	349	377	112	64.14	554
10.v	MIDREX wks VPSA sep.		321	28.58	575	321	350	121	64.01	535
10g.v	MIDREX gnf.wks VPSA sep.		299	28.58	573	299	328	120	64.09	511
10b.v	MIDREX wks VPSA sep. (BAT)		276	28.58	522	276	305	112	64.14	481
11	ULCORED wks, NG, MDEA sep.		358	28.58	529	358	386	151	64.01	601
11g	ULCORED gnf.wks, NG, MDEA sep.		335	28.58	528	335	364	149	64.09	577
11b	ULCORED wks, NG, MDEA sep. (BAT)		308	28.58	476	308	337	142	64.14	542
11.v	ULCORED wks, NG, VPSA sep.		281	28.58	547	281	309	151	64.01	524
11g.v	ULCORED gnf.wks, NG, VPSA sep.		259	28.58	545	259	287	149	64.09	500
11b.v	ULCORED wks, NG, VPSA sep. (BAT)		239	28.58	491	239	267	142	64.14	473
11.i	ULCORED wks, imp.elec., NG, MDEA sep.		327	474	259	327	801	151	64.01	1,016
11g.i	ULCORED gnf.wks, imp.elec., NG, MDEA sep.		305	471	259	305	776	149	64.09	989
11b.i	ULCORED wks, imp.elec., NG, MDEA sep. (BAT)		284	385	259	284	669	142	64.14	875
11.v.i	ULCORED wks, imp.elec., NG, VPSA sep.		248	503	259	248	751	151	64.01	966
11g.v.i	ULCORED gnf.wks, imp.elec., NG, VPSA sep.		226	500	259	226	726	149	64.09	940
11b.v.i	ULCORED wks, imp.elec., NG, VPSA sep. (BAT)		213	411	259	213	624	142	64.14	830
12	ULCORED wks, coal, MDEA sep.		521	28.58	1,102	521	550	226	82.06	858
12g	ULCORED gnf.wks, coal, MDEA sep.		468	28.58	1,138	468	497	225	82.14	804
12b	ULCORED wks, coal, MDEA sep. (BAT)		471	28.58	1,048	471	500	217	82.19	799
12.v	ULCORED wks, coal, VPSA sep.		361	28.58	1,138	361	389	226	82.06	698
12g.v	ULCORED gnf.wks, coal, VPSA sep.		339	28.58	1,137	339	367	225	82.14	674
12b.v	ULCORED wks, coal, VPSA sep. (BAT)		319	28.58	1,083	319	347	217	82.19	647
12.i	ULCORED wks, imp.elec., coal, MDEA sep.		485	554	783	485	1,039	226	82.06	1,348
12g.i	ULCORED gnf.wks, imp.elec., coal, MDEA sep.		468	555	783	468	1,023	225	82.14	1,330
12b.i	ULCORED wks, imp.elec., coal, MDEA sep. (BAT)		441	466	783	441	907	217	82.19	1,207
12.v.i	ULCORED wks, imp.elec., coal, VPSA sep.		320	615	783	320	936	226	82.06	1,244
12g.v.i	ULCORED gnf.wks, imp.elec., coal, VPSA sep.		299	612	783	299	911	225	82.14	1,218
12b.v.i	ULCORED wks, imp.elec., coal, VPSA sep. (BAT)		285	523	783	285	808	217	82.19	1,108
13	ULCORED wks, exs coal syng., MDEA sep.		549	28.58	2,135	549	578	337	103	1,017
13g	ULCORED gnf.wks, exs coal syng., MDEA sep.		497	28.58	2,171	497	525	335	103	963
13b	ULCORED wks, exs coal syng., MDEA sep. (BAT)		498	28.58	2,081	498	526	328	103	957
13.v	ULCORED wks, exs coal syng., VPSA sep.		403	28.58	2,130	403	431	337	103	871
13g.v	ULCORED gnf.wks, exs coal syng., VPSA sep.		401	28.58	2,105	401	429	335	103	867
13b.v	ULCORED wks, exs coal syng., VPSA sep. (BAT)		389	28.58	2,024	389	418	328	103	848
13.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep.		503	702	1,727	503	1,204	337	103	1,644
13g.i	ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.		487	702	1,727	487	1,189	335	103	1,627
13b.i	ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)		458	613	1,727	458	1,071	328	103	1,501
13.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep.		357	558	1,727	357	915	337	103	1,354
13g.v.i	ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.		359	524	1,727	359	882	335	103	1,320
13b.v.i	ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)		356	419	1,727	356	774	328	103	1,205
14	ULCORED wks, bio., MDEA sep.	766	472	28.58	936	472	501	223	64.01	788
14g	ULCORED gnf.wks, bio., MDEA sep.	766	415	28.58	979	415	444	222	64.09	729
14b	ULCORED wks, bio., MDEA sep. (BAT)	766	423	28.58	882	423	451	214	64.14	730
14.v	ULCORED wks, bio., VPSA sep.	766	322	28.58	967	322	350	223	64.01	638
14g.v	ULCORED gnf.wks, bio., VPSA sep.	766	314	28.58	966	314	343	222	64.09	629
14b.v	ULCORED wks, bio., VPSA sep. (BAT)	766	294	28.58	912	294	323	214	64.14	601
14.i	ULCORED wks, imp.elec., bio., MDEA sep.	766	437	540	626	437	977	223	64.01	1,264
14g.i	ULCORED gnf.wks, imp.elec., bio., MDEA sep.	766	422	541	626	422	963	222	64.09	1,248
14b.i	ULCORED wks, imp.elec., bio., MDEA sep. (BAT)	766	394	451	626	394	845	214	64.14	1,123
14.v.i	ULCORED wks, imp.elec., bio., VPSA sep.	766	298	591	626	298	889	223	64.01	1,176
14g.v.i	ULCORED gnf.wks, imp.elec., bio., VPSA sep.	766	276	588	626	276	864	222	64.09	1,150
14b.v.i	ULCORED wks, imp.elec., bio., VPSA sep. (BAT)	766	262	500	626	262	761	214	64.14	1,040
15	ULCORED wks, exs bio.syng., MDEA sep.	1,642	404	28.58	1,779	404	433	330	64.01	827
15g	ULCORED gnf.wks, exs bio.syng., MDEA sep.	1,642	381	28.58	1,822	381	410	329	64.09	802
15b	ULCORED wks, exs bio.syng., MDEA sep. (BAT)	1,642	387	28.58	1,726	387	416	321	64.14	801
15.v	ULCORED wks, exs bio.syng., VPSA sep.	1,642	349	28.58	1,754	349	378	330	64.01	772
15g.v	ULCORED gnf.wks, exs bio.syng., VPSA sep.	1,642	344	28.58	1,694	344	372	329	64.09	765
15b.v	ULCORED wks, exs bio.syng., VPSA sep. (BAT)	1,642	334	28.58	1,633	334	363	321	64.14	748
15.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep.	1,642	394	670	1,391	394	1,064	330	64.01	1,458
15g.i	ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.	1,642	379	671	1,391	379	1,050	329	64.09	1,443
15b.i	ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)	1,642	349	581	1,391	349	930	321	64.14	1,315
15.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep.	1,642	309	505	1,391	309	813	330	64.01	1,207
15g.v.i	ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.	1,642	309	466	1,391	309	776	329	64.09	1,168
15b.v.i	ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)	1,642	307	347	1,391	307	654	321	64.14	1,039
16	ULCOWIN wks, imp.elec.		173	1,927		173	2,099	189	76.48	2,365
16g	ULCOWIN gnf.wks, imp.elec.		149	1,920		149	2,069	187	76.56	2,333
16b	ULCOWIN wks, imp.elec. (BAT)		131	1,827		131	1,958	180	76.61	2,214

Table A-40: Emissions by source of technology sites constructed for the UK iron and steel sector

ID	Description	C-fix	Direct	Indirect	Captured	SE_1	SE_2	L2 Process	L1-2 transport	NRE
		$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$	$kgCO_2e/tcs$
5.2	TGR-BF [V4] wks, MDEA sep. w/o storage		1,723	192	752	1,723	1,914	170	112	2,196
5.2b	TGR-BF [V4] wks, MDEA sep. w/o storage (BAT)		1,538	173	752	1,538	1,710	165	111	1,987
5.2s	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage		1,388	163	584	1,388	1,551	148	97.34	1,796
5.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. w/o storage (BAT)		1,235	147	584	1,235	1,382	144	96.92	1,623
5.2.v	TGR-BF [V4] wks, VPSA sep. w/o storage		1,589	229	752	1,589	1,818	170	112	2,101
5.2b.v	TGR-BF [V4] wks, VPSA sep. w/o storage (BAT)		1,416	210	752	1,416	1,626	165	111	1,903
5.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage		1,283	192	584	1,283	1,476	148	97.34	1,721
5.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. w/o storage (BAT)		1,131	177	584	1,131	1,307	144	96.92	1,548
6.2	TGR-BF [V4] wks, MDEA sep.		970	192	752	970	1,162	170	112	1,444
6.2b	TGR-BF [V4] wks, MDEA sep. (BAT)		786	173	752	786	958	165	111	1,234
6.2s	TGR-BF [V4] wks, max scrap, MDEA sep.		804	163	584	804	967	148	97.34	1,212
6.2bs	TGR-BF [V4] wks, max scrap, MDEA sep. (BAT)		651	147	584	651	798	144	96.92	1,039
6.2.v	TGR-BF [V4] wks, VPSA sep.		836	229	752	836	1,066	170	112	1,348
6.2b.v	TGR-BF [V4] wks, VPSA sep. (BAT)		664	210	752	664	874	165	111	1,150
6.2s.v	TGR-BF [V4] wks, max scrap, VPSA sep.		700	192	584	700	892	148	97.34	1,137
6.2bs.v	TGR-BF [V4] wks, max scrap, VPSA sep. (BAT)		547	177	584	547	724	144	96.92	964
7	Hlsarna wks	1,455	1,632	14.16		1,632	1,647	238	82.21	1,967
7b	Hlsarna wks (BAT)	1,455	1,584			1,584	1,584	237	82.21	1,903
7s	Hlsarna wks, max scrap	1,128	1,289	55.60		1,289	1,345	215	74.34	1,635
7bs	Hlsarna wks, max scrap (BAT)	1,128	1,244	17.60		1,244	1,262	215	74.34	1,551
8	Hlsarna wks, MDEA sep.	1,455	447	303	1,174	447	750	238	82.21	1,070
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	262	1,174	395	657	238	82.21	977
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	295	910	372	666	215	74.34	956
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	257	910	322	579	215	74.34	868
8.v	Hlsarna wks, VPSA sep.	1,455	465	244	1,174	465	709	238	82.21	1,029
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	203	1,174	412	616	237	82.21	935
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	249	910	385	634	215	74.34	924
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	211	910	336	547	215	74.34	836
5.2.u	TGR-BF [V4] wks, MDEA sep. [0%CCU]		1,723	192	752	1,723	1,914	170	112	2,196
5.2b.u	TGR-BF [V4] wks, MDEA sep. [0%CCU] (BAT)		1,538	173	752	1,538	1,710	165	111	1,987
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU]		1,388	163	584	1,388	1,551	148	97.34	1,796
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [0%CCU] (BAT)		1,235	147	584	1,235	1,382	144	96.92	1,623
5.2.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU]		1,589	229	752	1,589	1,818	170	112	2,101
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [0%CCU] (BAT)		1,416	210	752	1,416	1,626	165	111	1,903
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU]		1,283	192	584	1,283	1,476	148	97.34	1,721
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [0%CCU] (BAT)		1,131	177	584	1,131	1,307	144	96.92	1,548
8	Hlsarna wks, MDEA sep.	1,455	447	303	1,174	447	750	238	82.21	1,070
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	262	1,174	395	657	238	82.21	977
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	295	910	372	666	215	74.34	956
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	257	910	322	579	215	74.34	868
8.v	Hlsarna wks, VPSA sep.	1,455	465	244	1,174	465	709	238	82.21	1,029
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	203	1,174	412	616	237	82.21	935
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	249	910	385	634	215	74.34	924
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	211	910	336	547	215	74.34	836
5.2.u	TGR-BF [V4] wks, MDEA sep. [67%CCU]		1,723	192	752	1,723	1,914	170	112	2,196
5.2b.u	TGR-BF [V4] wks, MDEA sep. [67%CCU] (BAT)		1,538	173	752	1,538	1,710	165	111	1,987
5.2s.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU]		1,388	163	584	1,388	1,551	148	97.34	1,796
5.2bs.u	TGR-BF [V4] wks, max scrap, MDEA sep. [67%CCU] (BAT)		1,235	147	584	1,235	1,382	144	96.92	1,623
5.2.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU]		1,589	229	752	1,589	1,818	170	112	2,101
5.2b.vu	TGR-BF [V4] wks, VPSA sep. [67%CCU] (BAT)		1,416	210	752	1,416	1,626	165	111	1,903
5.2s.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU]		1,283	192	584	1,283	1,476	148	97.34	1,721
5.2bs.vu	TGR-BF [V4] wks, max scrap, VPSA sep. [67%CCU] (BAT)		1,131	177	584	1,131	1,307	144	96.92	1,548
8	Hlsarna wks, MDEA sep.	1,455	447	303	1,174	447	750	238	82.21	1,070
8b	Hlsarna wks, MDEA sep. (BAT)	1,455	395	262	1,174	395	657	238	82.21	977
8s	Hlsarna wks, max scrap, MDEA sep.	1,128	372	295	910	372	666	215	74.34	956
8bs	Hlsarna wks, max scrap, MDEA sep. (BAT)	1,128	322	257	910	322	579	215	74.34	868
8.v	Hlsarna wks, VPSA sep.	1,455	465	244	1,174	465	709	238	82.21	1,029
8b.v	Hlsarna wks, VPSA sep. (BAT)	1,455	412	203	1,174	412	616	237	82.21	935
8s.v	Hlsarna wks, max scrap, VPSA sep.	1,128	385	249	910	385	634	215	74.34	924
8bs.v	Hlsarna wks, max scrap, VPSA sep. (BAT)	1,128	336	211	910	336	547	215	74.34	836

Table A-41: Emissions by source of technology sites with alternative configuration, constructed for the UK iron and steel sector

A5.10 Parameter tables

General energy and unit conversion factors	Energy inputs																				Energy outputs										
	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass	Waste plastic	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Raw data unit	kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
NCV/GCV	0.95	0.95	0.95	0.95	0.9	0.93	0.95	0.9	0.95		0.95	0.95	0.9	1	1	0.9	1	1	1	1	0.95	0.95	0.9	1	1	0.9	1	0.95	1	1
NCV - TJ/unit	28.26	28.26	40.90	42.50	3.24	3.36	3.42	12.67	28.26		28.23	28.23	3.24	3.60	3.60	3.24	3.60	3.60	3.60	3.60	28.23	28.23	3.24	3.60	3.60	3.24	3.60	3.42	3.60	3.60
NCV - Gasses, GJ/Nm3					38.75	100.31	16.39						17.33	3.21	9.87	12.96	7.47						17.33	3.21	9.87	12.96	7.47			
Density - Gasses					0.81	2.19	0.58						0.42	1.26	1.04	0.58	1.28						0.42	1.26	1.04	0.58	1.28			
Source	ISSB 2013		ISSB 2011	ISSB 2011	AEA 2012	AEA 2012				Not included	ISSB 2013	ISSB 2013	IEAGHG 2013	IEAGHG 2013	IEAGHG 2013		IEAGHG 2013				ISSB 2013	ISSB 2013	IEAGHG 2013	IEAGHG 2013	IEAGHG 2013		IEAGHG 2013	IEAGHG 2013		
Comment	31 dry basis	As coking coal. See section body														Density as BFG					29.5 dry basis	29.5 dry basis				Density as BFG				

	Material inputs																											Material outputs																			
	Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/c ooling water	O_2	CO_2 (captured)	Flue gas
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
																1.33	1.16		1.20																				1.33		
																IEAGHG 2013	IEAGHG 2013		IEAGHG 2013																				IEAGHG 2013		

Table A-42: General energy and unit conversion factors used for analysis of the UK iron and steel sector

Other thermodynamic conversion factors	Energy inputs																				Energy outputs									
	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Energy/Exergy [fuels: b_{th}/NCV=β]	1.09	1.17	1.07	1.07	1.04	1.04					1.06	1.06	1.00	0.98			1.00				1.06	1.06	1.00	0.98			1.00	1.00		
Enthalpy of devaluation [fuels: NCV], GJ/t	28.26	28.26	40.90	42.50	47.73	45.90					28.23	28.23	41.01	2.54			5.85	N/A			28.23	28.23	41.01	2.54			5.85	40.00	N/A	
Standard chemical exergy, GJ/t	30.81	33.07	43.76	45.48	49.64	47.74					29.92	29.92	41.01	2.49			5.85				29.92	29.92	41.01	2.49			5.85	42.87		
Source	Szargut 1988	Szargut 1988	Szargut 1988	Szargut 1988	Szargut 1988						Szargut 1988		Fulton Hughes 1995 in Michaelis 1998	Fulton Hughes 1995 in Michaelis 1998			Fulton Hughes 1995 in Michaelis 1998				Szargut 1988		Fulton Hughes 1995 in Michaelis 1998	Fulton Hughes 1995 in Michaelis 1998			Fulton Hughes 1995 in Michaelis 1998	Fulton Hughes 1995 in Michaelis 1998		
Comment	Calculated from β	Calculated from β	Calculated from β = NCV/B	Calculated from β	Calculated from β	As natural gas	Not included	Not included	Not included	Not included	Calculated from β	As coke	Using β implied from source	Using β implied from source	Not included	Not included	Using β implied from source	Thermal energy	Electrical work	Electrical work	Calculated from β	As coke	Using β implied from source	Using β implied from source	Not included	Not included	Using β implied from source	Using β implied from source	Thermal energy	Electrical work

| Material inputs | | | | | | | | | | | | | | | | | | |

Emissions accounting conversion factors	Energy inputs																			Energy outputs										
	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
CO2 emissions factor (scope 1; scope 2-3 for electricity purchase)	2.63	2.63	3.20	3.15	0.18	0.19	0.15	1.41	2.63	0.00	3.12	3.12	0.15	1.07	0.55	0.00	0.73	0.00	0.00	0.54	3.12	3.12	0.15	1.07	0.55	0.00	0.73	0.30	0.00	0.00
Unit	ktCO2e/kt	ktCO2e/kt	ktCO2e/kt	ktCO2e/kt	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/kt	ktCO2e/kt	ktCO2e/GWh	ktCO2e/kt	ktCO2e/kt	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/kt	ktCO2e/kt	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh	ktCO2e/GWh
GhG emissions factor (scope 1, scope 2-3 for electricity purchase)	2.71	2.71	3.21	3.45	0.19	0.19	0.15	1.45	2.71	0.00	3.12	3.12	0.15	1.07	0.55	0.00	0.73	0.00	0.00	0.54	3.12	3.12	0.15	1.07	0.55		0.73	0.30	0.00	0.00
Unit	ktCO2/kt	ktCO2/kt	ktCO2/kt	ktCO2/kt	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/kt	ktCO2/kt	ktCO2/GWh	ktCO2/kt	ktCO2/kt	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/kt	ktCO2/kt	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh	ktCO2/GWh
Source	IISI 1998	IISI 1998	AEA2012b	AEA2012b	AEA2012a	AEA2012b					AEA 2012b			AEA 2012b	AEA 2012b	IEAGHG 2013		IEAGHG 2013		AEA 2012a								IISI 1998		
Comment	Derived from	Derived from		Gas oil		OPG	As COG	Estimated as coal per unit of energy*	Not included	As per chemical definition		As coke			Derived from chemical compositio n	Not included	Derived from chemical compositio n			Scope 2, 3: Electricity consumed, Grid rolling average 2007						Not included				
CO2e/CO2	1,0315	1,0315	1,0036	1,0948	1,0021	1,0011	1,0024	1,0315	1,0315		1,0022	1,0022	1,0024	1,0002	1,0000					1,0067	1,0022	1,0022	1,0024	1,0002	1,0000		1,0000	1,0000		
Source/comment	AEA 2012a	AEA 2012a	AEA 2012a	AEA 2012a	AEA 2012a	AEA 2012a	As COG	As coal	0.0%		AEA 2012a	AEA 2012a	AEA 2012a	Estimated	Estimated			Estimated		AEA 2012a	AEA 2012a	AEA 2012a	AEA 2012a	Estimated	Estimated		Estimated	Estimated		

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Solids and liquids: %wt chemical compositions	Energy inputs																				Energy outputs										
	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Fe2O3	0%	0%	0%	0%						0%	0%										0%	0%								
MnO3	0%	0%	0%	0%						0%	0%										0%	0%								
Fe	0%	1%	0%	0%						0%	0%										0%	0%								
C	79%	87%	83%	84%						88%	88%										88%	88%								
H	5%	4%	12%	12%						0%	0%										0%	0%								
CaCO3	0%	0%	0%	0%						0%	0%										0%	0%								
CaO	0%	0%	0%	0%						0%	0%										0%	0%								
MgCO3	0%	0%	0%	0%						0%	0%										0%	0%								
MgO	0%	0%	0%	0%						0%	0%										0%	0%								
SiO2	5%	2%	0%	0%						6%	6%										6%	6%								
Al2O3	2%	2%	0%	0%						3%	3%										3%	3%								
N	0%	0%	0%	0%						1%	1%										1%	1%								
H2O	8%	1%	0%	0%						4%	4%										4%	4%								
S	0%	0%	2%	2%						1%	1%										1%	1%								
Si	0%	0%	0%	0%						0%	0%										0%	0%								
Mn	0%	0%	0%	0%						0%	0%										0%	0%								
Al	0%	0%	0%	0%						0%	0%										0%	0%								
P	0%	0%	0%	0%						0%	0%										0%	0%								
Others (difference)			3%	2%																										
Source	IEAGHG 2013	IEAGHG 2013	Morvey and Gvozdenae 2009, ISSB 2013	Morvey and Gvozdenae 2009, ISSB 2013							IEAGHG 2013	IEAGHG 2013									IEAGHG 2013	IEAGHG 2013								
Comment								Not included	Not included																					

| Material inputs | | | | | | | | | | | | | | | | | | |

Gasses: %wt chemical compositions	Energy inputs																				Energy outputs										
Compound	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
CH4					69%	0%				0%			35%	0%	0%		0%	0%					35%	0%	0%		0%	0%	0%	
C2H6					14%	0%				0%			0%	0%	0%		0%	0%					0%	0%	0%		0%	0%	0%	
C3H8					8%	60%				0%			0%	0%	0%		0%	0%					0%	0%	0%		0%	0%	0%	
C4H10					4%	40%				0%			0%	0%	0%		0%	0%					0%	0%	0%		0%	0%	0%	
C5H12					1%	0%				0%			0%	0%	0%		0%	0%					0%	0%	0%		0%	0%	0%	
H2					0%	0%				100%			11%	0%	0%		0%	0%					11%	0%	0%		0%	0%	0%	
CO2					4%	0%				0%			4%	32%	0%		22%	0%					4%	33%	0%		22%	0%	0%	
CO					0%	0%				0%			10%	21%	0%		58%	0%					10%	21%	0%		58%	0%	0%	
O2					0%	0%				0%			1%	0%	0%		0%	0%					1%	0%	0%		0%	0%	0%	
N2					1%	0%				0%			15%	45%	0%		14%	0%					15%	44%	0%		14%	0%	0%	
H2O					0%	0%				0%			5%	2%	0%		8%	100%					5%	2%	0%		8%	0%	100%	
Other Hydrocarbons					0%	0%				0%			18%	0%	0%		0%	0%					18%	0%	0%		0%	0%	0%	
Others (difference)					0%	0%				0%			0%	0%	0%		0%	0%					0%	0%	0%		0%	0%	0%	
Source					IEAGHG 2013	Morvey and Gvozdenae 2009							IEAGHG 2013	IEAGHG 2013, ISSB 2013	IEAGHG 2013		IEAGHG 2013						IEAGHG 2013	IEAGHG 2013, ISSB 2013	IEAGHG 2013		IEAGHG 2013			
Comment						LPG mix ratio	Not included			As per chemical definition						Not included		As per chemical definition							Not included			As per chemical definition		

| Material inputs | | | | | | | | | | | | | | | | | | |

L2 process and L1-2 transport conversion	Energy inputs																				
Compound	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)
Flow ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Unit - energy	GJ/t	GJ/t	GJ/t	GJ/t	GJ/kWh	GJ/kWh	GJ/kWh	GJ/t	GJ/t	GJ/kWh	GJ/t	GJ/t	GJ/kWh	GJ/kWh	GJ/kWh	GJ/kWh	GJ/kWh	GJ/kWh	GJ/kWh	GJ/kWh
L2 process - energy	2.191	2.191	3.427					1.332												
Source	Michaelis 1998	Michaelis 1998	DECC 2013 (DUKES)					AEA 2012												
L1-2 transport - energy	0.637	0.637																		
Source	Energy Audit Series 1982	Energy Audit Series 1982																		
Comment	Transport as iron ore	Transport as iron ore						Back-calc. frm scope 3 EF w/NG EF												
Unit - GhG emission	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/kWh$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$	$kgCO_2e/kWh$
L2 process: GhG emission, kgCO2e/unit	0.124	0.124	0.266					0.076												
Source/comment	From energy - grid EF	From energy - grid EF	From energy - petroleum EF					AEA 2012 - includes transport												
L1-2 transport GhG emission, kgCO2e/unit	0.052	0.052																		
Source/comment	From energy - pet. EF	From energy - pet. EF																		

Material inputs																									
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing materials	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	kWh/nm3	kWh/nm3	GJ/t	kWh/nm3	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
0.180	0.522	0.180							0.505			1.770	5.867	78.846	5.106				14.898				12.897
Michaelis 1998	European Commissio n 2012	Michaelis 1998							Energy Audit Series 1982			Energy Audit Series 1982	BLA 2014, ONS 2014	Energy Audit Series 1982	Energy Audit Series 1982, IISI				Energy Audit Series 1982				European Commissio n 2013
0.637	0.637	0.637						0.499	0.500			0.180	0.180										
Energy Audit Series 1982	Energy Audit Series 1982	Energy Audit Series 1982						Energy Audit Series 1982	Energy Audit Series 1982			Energy Audit Series 1982	Energy Audit Series 1982										
															Linerar reduction to BAT in base year								Mass allocated from chloride process
$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/m^3$	$kgCO_2e/m^3$	$kgCO_2e/t$	$kgCO_2e/m^3$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$
0.010	0.059	0.010							0.029			0.100	1.202	4.461	0.289				0.843				0.737
From energy - grid EF	From energy - grid EF	From energy - grid EF							From energy - grid EF			From energy - grid EF	From energy - Fuel EF + process CO2	From energy - grid EF	From energy - grid EF				From energy - grid EF				From energy - fuel split chloride process
0.052	0.052	0.052						0.041	0.041			0.015	0.015										
From energy - pet. EF	From energy - pet. EF	From energy - pet. EF						From energy - pet. EF	From energy - pet. EF			From energy - pet. EF	From energy - pet. EF										

Table A-47: Level 2 process and level 1-2 transport energy and emissions factors for the UK iron and steel sector

Substance	State	Mass, kg/kmol	Enthalpy of devaluation, kJ/mol	Standard chemical exergy, kJ/mol
Al	s	26.9815	930.9	795.7
Al_4C_3	s	143.959	4694.51	4216.2
$AlCl_3$	s	133.3405	467.18	352.2
Al_2O_3	s. α corundum	101.9612	185.69	15
$Al_2O_3 \cdot H_2O$	s. boermite	119.9765	128.35	9.4
$Al_2O_3 \cdot 3H_2O$	s. gibbsite	156.0072	24.13	24.1
Al_2S_3	s	150.155	3313.81	2705.3
$Al_2(SO_4)_3$	s	342.148	596.8	344.3
Al_2SiO_5	s. andalusite	162.046	28.03	9.2
Al_2SiO_5	s. kyanite	162.046	25.94	12.9
Al_2SiO_5	s. sillimanite	162.046	0	15.3
$Al_2SiO_5 \cdot (OH)_4$	s. kaolinite	258.1615	68.25	12
$3Al_2O_3 \cdot 2SiO_2$	s. mullite	426.0536	630.11	63.2
Ba	s. II	137.34	747.77	775.1
$BaCO_3$	s. II	197.35	-75.18	53.3
$BaCl_2$	s	208.25	48.69	88.7
BaO	s	153.34	194.15	252
BaO_2	s	169.34	113.38	196.7
$Ba(OH)_2$	s	171.36	45.93	160.3
BaS	s	169.4	1012.88	929
$BaSO_4$	s. barite	233.4	0	30.7
C	s. graphite	12.01115	393.509	409.87
C	s. diamond	12.01115	395.406	412.77
CCl_4	l	153.823	578.95	472.7
C_2N_2	g. cyanogen	52.0357	1096.14	1118.1
CH_4	g. methane	16.04303	802.3	831.2
C_2H_6	g. ethane	30.0701	1427.8	1495
C_3H_8	g. propane	44.172	2045.4	2152.8
C_4H_{10}	g. n-butane	58.1243	2658.4	2804.2
C_5H_{12}	g. n pentane	72.1514	3274.4	3461.3
C_2H_4	g. ethylene	28.0542	1323.1	1360.3
C_3H_6	g. propylene	42.0813	1927.7	2002.7
C_2H_2	g. acetylene	26.0382	1255.6	1265
C_6H_6	g. benzene	78.1147	3171.6	3301.3
C_6H_6	l. benzene	78.1147	3137.7	3296.2
C_7H_8	l methylbenzene	92.1418	3736.4	3928.3
C_8H_{10}	l. ethylbenzene	106.1689	4347.7	4584.8
$C_{10}H_8$	s. naphtalene	128.1753	4984.2	5251.1
$C_{14}H_{10}$	s. anthracene	178.2358	6850.9	7212.6
CH_2O_2	l. formic acid	46.0259	213	291.3
C_2H_6O	l. ethylalcohol	46.0695	1235.9	1356.9
$C_2H_4O_2$	l. acetic acid	60.0529	786.6	907.2
C_3H_6O	l. acethone	58.0807	1659.6	1797.3
C_6H_6O	s. phenol	94.1141	2925.9	3126.2
$C_2H_2O_4$	s. oxalic acid	90.0358	202.7	367.9
CH_4ON_2	s. urea	60.0558	544.7	688.6
CO	g	28.0105	282.984	274.71
CO_2	g	44.0095	0	19.48
CS_2	l	76.139	2934.09	1694.3
Ca	S. II	40.08	813.57	729.5
CaC_2	s	64.1	1541.18	1484.6
$CaCO_3$	s. aragonite	100.09	0	16.3
$CaCO_3 \cdot MgCO_3$	s. dolomite	184.411	0	32.2
$CaCl_2$	s	110.99	178.21	105
$CaFe_2O_4$	s	215.77	161.07	121.1
$Ca_2Fe_2O_4$	s	271.85	321	212.2
$Ca_2Mg_5Si_8O_{22}(OH)$	s. tremolite	812.41	425.49	79.7
$Ca(NO_3)_2$	s	164.0898	-124.9	-1
CaO	s	56.08	178.44	127.3
$CaO \cdot Al_2O_3$	s	158.04	351.66	123.1
$CaO \cdot 2Al_2O_3$	s	260	541.71	138.8
$3CaO \cdot Al_2O_3$	s	270.2	716.72	382.6
$12CaO \cdot 7Al_2O_3$	s	1386.68	3415.71	1546.7
$CaO \cdot Al_2O_3 \cdot SiO_2$	s. anortite	218.125	273.92	66
$Ca(OH)_2$	s	74.09	69.04	70.8
$Ca_3(PO_4)_2$	s. α	310.18	0	37.3
CaS	s	72.14	1056.57	861.7
$CaSO_4$	s. anhydrite	136.14	104.88	25.3
$CaSO_4 \cdot 1/2H_2O$	s. α	145.15	83.16	29.2
$CaSO_4 \cdot 2H_2O$	s. gypsum	172.17	0	25.7
$CaSiO_3$	s. volastonite	116.16	90.24	40.7
Ca_2SiO_4	s. β	172.4	232.28	129.9
Ca_3SiO_5	s	282.2	424.94	271.1
Cd	s. α	112.4	357.1	293.8
Cd	s. ν	112.4	356.51	293.2
$CdCO_3$	s	172.41	0	40.2
$CdCl_2$	s	183.31	126.04	73.4
CdO	s	128.4	98.95	67.3
$Cd(OH)_2$	s	146.41	38.26	59.5
CdS	s	144.46	920.6	746.9
$CdSO_4$	s	208.46	149.24	88.6
$CdSO_4 \cdot H_2O$	s	226.48	84.79	80.6
Cl_2	g	70.906	160.44	123.6
Cl	g	35.453	201.9	87.1
Cr	s	51.996	569.86	584.7
Cr_3C_2	s	180.01	2415.85	2492.2
Cr_7C_3	s	400.005	5007.63	5155.5
$CrCl_2$	s	122.902	361.91	352.2
$CrCl_3$	s	158.355	281.05	301.9
Cr_2O_3	s	151.99	0	117.2

Table A-48: Enthalpy of devaluation and standard chemical exergy of substances (Szargut 2007)

Substance	State	Mass, kg/kmol	Enthalpy of devaluation, kJ/mol	Standard chemical exergy, kJ/mol
Cu	s	63.54	201.59	134.2
$CuCO_3$	s	123.55	0	31.1
CuCl	s	98.99	144.57	76.2
$CuCl_2$	s	134.45	151.95	82.1
$CuFe_2O_4$	s	239.23	60.62	36.1
CuO	s	79.54	44.27	6.5
Cu_2O	s	143.08	234.56	124.4
$Cu(OH)_2$	s	97.55	-6.37	15.3
CuS	s	95	873.87	690.3
Cu_2S	s	159.14	1049.1	791.8
$CuSO_4$	s	159.6	155.65	89.8
Cu_2SO_4	s	223.14	377.15	253.6
D_2	g	4.02946	249.199	263.8
D_2O	g	20.02886	0	31.2
D_2O	l	20.02886	-45.401	22.3
Fe	s, α	55.847	412.12	374.3
Fe_3C	s, α cementite	179.552	1654.97	1553.5
$FeCO_3$	s, siderite	115.856	65.06	123.4
$FeC1_2$	s	126.753	230.77	195.5
$FeC1_3$	s	162.206	253.29	228.1
$FeCr_2O_4$	s	223.837	107.1	207.8
$Fe_{0.947}O$	s, wustite	68.8865	124.01	111.3
FeO	s	71.846	140.16	124.9
Fe_2O_3	s, hematite	159.692	0	12.4
Fe_3O_4	s, magnetite	231.539	117.98	116.3
$Fe(OH)_3$	s	106.869	-48.14	37.5
FeS	s	87.911	1037.54	883.5
FeS_2	s, pyrite	119.075	1684.72	1426.6
$FeSO_4$	s	151.909	209.11	170.9
FeSi	s	83.933	1249.42	1155.5
$FeSiO_3$	s	131.931	118.07	159.9
$FeSiO_4$	s, fyalite	203.778	255.3	232.3
$FeTiO_3$	s	151.75	118.9	129.6
H_2	g	2.01594	241.818	236.09
H	g	1.00797	338.874	331.3
HCl	g	36.461	108.82	84.5
HDO	g	19.0213	0.21	18.8
HDO	l	19.0213	-44.38	10
HNO_3	l	63.0129	-53.19	43.5
H_2O	g	18.01534	0	9.5
H_2O	l	18.01534	-44.012	0.9
H_3PO_4	s	98.0013	-76.26	89.6
H_2S	g	34.08	946.61	812
H_2SO_4	l	98.077	153.25	163.4
K	s	39.102	356.63	366.6
$KAlSi_3O_8$	s, adulare	278.337	66.26	7.4
K_2CO_3	s	138.213	-43.58	84.7
KCl	s	75.555	0	19.6
$KClO_4$	s	138.553	6.67	136
$K_2Cr_2O_7$	s	294.184	-190.4	34.3
KNO_3	s	101.1069	-135.9	-19.4
K_2O	s	94.203	350.04	413.1
KOH	s	56.109	52.72	107.6
K_2S	s	110.268	1024.4	943
K_2SO_3	s	158.266	300.47	302.6
K_2SO_4	s	174.266	4.62	35
K_2SiO_3	s	154.288	75.9	138.2
Mg	s	24.312	725.71	626.1
$MgAl_2O_4$	s, spinel	142.273	274.17	45.3
$MgCO_3$	s	84.321	23.43	29.8
$MgCl_2$	s	95.218	244.65	158.2
$MgFeO_4$	s	200.004	121.53	68.1
MgO	s	40.311	124.38	59.1
$Mg(OH)_2$	s	58.327	42.73	33.2
$Mg(NO_3)_2$	s	148.3218	-64.34	49.7
$Mg_3(PO_4)_2$	s	262.879	76.59	78.1
MgS	s	56.376	1105.11	893.9
$MgSO_4$	s	120.374	166.22	73
$MgSiO_3$	s	100.396	87.73	14.8
Mg_2SiO_4	s	140.708	188.35	59.8
$Mg_3Si_2O_5(OH)$	s, chrysilite	277.134	117.06	38.8
$Mg_3Si_2O_{10}(OH)$	s, talc	379.298	140.26	14.8
Mg_2TiO_4	s	160.52	231.48	119.3
Mn	s, α	54.9381	520.03	487.7
Mn_3C	s	176.82545	1958.2	1878.1
$MnCO_3$	s	114.9475	19.42	86.8
$MnCl_2$	s	124.844	199.18	170.8
$MnFe_2O_4$	s	230.63	118.36	122.6
MnO	s	70.9375	134.81	124.8
MnO_2	s	86.0369	0	26.5
Mn_2O_3	s	157.8744	81.09	100.2
Mn_3O_4	s	228.8119	172.26	187.8
$Mn(OH)_2$	s, amorphous	88.9528	66.47	112.7
MnS	s, green	87.002	1031.23	878.9
$MnSO_4$	s	151	180.2	147.8
$MnSiO_3$	s	131.022	110.08	108
N_2	g	28.0134	0	0.72
N_2 atmospheric	g	28.1541	0	0.69
NH_3	g	17.0305	316.62	337.9
NH_4C1	s	53.491	249.43	331.3
NH_4NO_3	s	80.04348	118.08	294.8
$(NH_4)_2SO_4$	s	132.138	511.84	660.6

Table A-cont'd: Enthalpy of devaluation and standard chemical exergy of substances (Szargut 2007)

Substance	State	Mass, kg/kmol	Enthalpy of devaluation, kJ/mol	Standard chemical exergy, kJ/mol
NO	g	30.0061	90.25	88.9
NO_2	g	46.0055	33.18	55.6
N_2O	g	44.0128	82.05	106.9
N_2O_4	g	92.011	9.163	106.5
N_2O_5	g	108.0104	11.3	125.7
Na	s	22.9898	330.9	336.6
$NaAlO_2$	s	81.9701	128.4	67.15
$NaAlSi_2O_6•H_2O$	s. analcime	220.055	35.41	20.3
$NaAlSi_3O_8$	s. low albite	262.2245	72.75	21.9
Na_2CO_3	s	105.9891	-75.62	41.1
NaCl	s	58.443	0	14.3
$NaHCO_3$	s	84.0071	-101.94	21.6
$NaNO_3$	s	84.9947	-135.62	-22.7
Na_2O	s	61.979	243.82	296.2
NaOH	s	39.9972	23.79	74.9
Na_2S	s	78.044	1014.84	921.4
Na_2SO_3	s	126.042	297.63	287.5
Na_2SO_4	s	142.041	0	21.4
Na_2SiO_3	s	122.064	11.31	66.4
Na_2Si2O_5	s	182.149	13.28	68.2
Na_4SiO_4	s	184.043	151.45	256.9
Ni	s	58.71	239.74	232.7
Ni_3C	s	188.14	1180.09	1142.5
$NiCO_3$	s	118.72	-49.93	36
$NiCl_2$	s	129.62	94.85	97.2
NiO	s	74.71	0	23
Ni(OH)	s	92.72	-48.13	25.5
NiS	s	909.77	883.15	762.8
Ni_3S_2	s	240.26	1967.14	1720.2
$NiSO_4$	s	154.77	92.25	90.4
$NiSO_4•6H_2O$	s. α, tetragonal. Green	262.86	-266.75	53.6
O_2	g	31.9988	0	3.97
O	g	15.9994	249.17	233.7
O_3	g	47.9982	142.67	168.1
P	s. α, white	30.9738	840.06	861.4
P	s. red, triclinic	30.9738	822.49	849.2
P_4O_{10}	s. hexagonal	283.8892	376.21	767.7
Pb	s	207.2	305.64	232.8
$PbCO_3$	s	257.2	0	23.1
$PbCl_2$	s	278.1	106.67	42.3
PbO	s. yellow	223.19	88.32	46.9
PbO	s. red	223.19	86.65	45.9
PbO_2	s	239.19	28.24	19.4
Pb_3O_4	s	685.57	198.53	72.2
Pb(OH)	s	241.2	32.48	20.6
PbS	s	239.25	930.64	743.7
$PbSO_4$	s	303.25	111.12	37.2
$PbSiO_3$	s	283.27	70.88	31.5
Pb_2SiO_4	s	506.46	159.07	75.8
S	s. rhombic	32.064	725.42	609.6
SO_2	g	64.0628	428.59	313.4
SO_3	g	80.0622	329.7	249.1
Si	s	28.086	910.94	854.9
SiC	s. α, hexagonal	40.097	1241.69	1204.5
$SiCl_4$	l	169.898	544.81	482.2
SiO_2	s. α, quartz	60.085	0	2.2
SiO_2	s. α, cristobalite	60.085	1.46	3.1
SiO_2	s. amorphous	60.085	7.45	8.2
SiS_2	s	92.214	2149.23	1866.6
Sn	s. I. white	118.69	580.74	558.7
Sn	s. II. gray	118.69	578.65	558.8
$SnCl_2$	s	189.6	416.08	400.3
SnO	s	134.69	294.97	303.8
SnO_2	s	150.69	0	43
SnS	s	150.75	1205.74	1070
SnS_2	s	182.82	1863.8	1618.5
Ti	s	47.9	944.75	907.2
TiC	s	59.91	1154.16	1136.6
TiO	s	63.9	425.14	419.2
TiO_2	s. rutile	79.9	0	21.7
TiO3	s	143.8	368.66	386.1
Ti_3O_5	s	223.7	375.1	414.1
TiS_2	s	112.03	2060.45	1876.2
U	s	238.03	1230.1	1196.6
UCl_3	s	344.39	577.35	556
UCl_4	s	379.84	499.39	491.1
UCl_5	s	415.3	536.93	519.5
UO_2	s	270.03	145.19	168.9
UO_3	s	286.03	0	49.8
U_3O_8	s	842.085	115.49	236.2
W	s	183.85	842.87	827.5
WC	s	195.86	1195.84	1199.1
WO_2	s	215.85	253.18	297.5
WO_3	s	231.85	0	69.3
WS_2	s	249.98	2084.51	1796.6
Zn	s	65.37	419.27	339.2
$ZnCO_3$	s	125.38	0	23.5
$ZnCl_2$	s	136.28	583.93	93.4
$ZnFe_2O_4$	s	241.06	74.08	32.2
ZnO	s	81.37	70.99	22.9
$Zn(OH)_2$	s.β	99.38	1918	25.7
ZnS	s. sphalerite	97.43	938.71	747.6
$ZnSO_4$	s	161.43	161.87	82.3
Zn_2SiO_4	s	222.82	112.74	18.1

Table A-cont'd: Enthalpy of devaluation and standard chemical exergy of substances (Szargut 2007)

A5.11 Material and energy tables

Included in this section are the material and energy tables constructed for the baseline and future technology sites and steelmaking systems. The full mass balance is only attempted for configurations of the baseline. The modelled sites of improvement and replacement technologies exclude data for some material flows. Excluded are flows for: process and cooling water, combustion air, flue gas, and other.

The flows 'flue gas' and 'other' are described for each baseline process in Table A-49. It should be noted that the cooler of the sinter plant is not included within the process system boundary because of difficulty in obtaining information for a representative cooling air mass flow. The flow 'air' is the process combustion air of each process except for the blast furnace where it is the total of combustion air and cold blast air.

Process	Flue gas (71)	Other (68)
Coke oven	Underfiring exhaust	Ammonia
Sinter plant	Main strand exhaust	Coke breeze ash
Blast furnace	Hot stove exhaust flue	Blast furnace gas loss
Basic oxygen furnace	Unrecovered BOFG	Scale/other
Electric arc furnace	Main exhaust flue	Scale/other
Continuous casting	Preheater exhaust flue	Scale/other
Ingot casting	Reheat furnace exhaust flue	Scale/other
Hot rolling	Reheat furnace exhaust flue	Scale/other
Downstream and other	Reheat furnace exhaust flue	Scale/other

Table A-49: Description of material flows 71 and 68 of the material and energy tables of the baseline

Raw data units - 2007 sector baseline	Main output			Energy inputs																			Energy outputs										
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,509	703				796	32.08	51.34	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	145	232										
Blast furnace	Hot metal	kt	10,960	1,242		201		719						3,910	490	942	4,379				2,849	184	295				16,018					243	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	190	305							514			
Electric arc furnace	Liquid steel	kt	3,100		9.37		0.04	170	2.77					22.92							26.12		1,318										
Continuous caster	SF steel	kt	14,188					174								17.44					6.13	42.17	94.81										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	10,424					4,163								236	138			290	167	290	732									60.94	
Downstream and other	Finished steel	kt	4,646			6.20	0.31	2,539	58.23							229	576			224	546	702	1,611									61.65	
Power plant and Boiler						31.35		718								2,326	9,102				8,884											14,101	1,484
Losses/flaring																445	1,121				1,029												
Subsector	SF steel	kt	14,392	6,881	9.37	239	0.50	8,610	61.00					3,933	1,146	8,129	16,018			514	14,466	1,586	4,654	4,237	24.09	8,244	16,018			514	1,749	14,466	1,586

Material inputs																									Material outputs																						
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
																	6,864	3,802																	277	6,864				5,575
11,300		3.27	4,071	925	151							1,949					3,117	10,389		984								4,071	13,851							90.22	3,117				14,536
1,944	3,269		12,400	145				2.71				57.27			251		8,998	18,263		18.76				2,994			116	1,070		10,960					1,556	8,998				12,647
93.35							10,471	207	620	1,235			720		616		9,323		203	164						1,457					11,653					58.27	9,323				901
								50.59	1,093	2,178			156	7.87	129		3,100	529	167	10.81							512					3,100						3,100				778
											14,555							205														14,191			239	125				260
											190							52.10														171			17.50	1.50				65.98
												11,435						3,352															10,424		855	156				4,712
								3.42				5,324						3,763															4,646		608	69.69				5,687
																		10,861																						26,245
																		1,307																						3,198
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,719	3,412	14,745	16,759	2,006	876	7.87	997		31,402	52,522	370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	14,362	15,070		1,719	2,334	31,402			74,606

Table A-50: Energy and material flow table for the UK iron and steel sector: 2007 baseline, raw data units

Raw data units - 2007 sector baseline	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kg/unit	kg/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit
Coke oven	Dry coke	kt	3,610	1,383												861	172				195	7.87	12.59	1,039	5.91	2,022					429		
Sinter plant	Sinter	kt	9,447					5.74							47.36	11.29					0.71	10.48	16.77										
Blast furnace	Hot metal	kt	7,233	113		18.35		65.60						357	44.74	85.93	400				260	16.80	26.89				1,462					22.15	9.29
Basic oxygen furnace	Liquid steel	kt	7,511				0.01									23.07					12.78	16.33	26.14							44.08			
Electric arc furnace	Liquid steel	kt	2,440		3.02		0.01	54.76	0.89					7.39							8.42		425										
Continuous caster	Semi-finished steel	kt	9,553					12.26								1.23					0.43	2.97	6.68										
Ingot caster	Semi-finished steel	kt	133					278													16.67		89.71										
Hot rolling mill	Hot-rolled steel	kt	8,415					399								22.61	13.21			27.82	16.05	27.80	70.20									5.85	
Downstream and other						1.33	0.07	547	12.53							49.21	124			48.14	118	151	347									13.27	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	9,708	478	0.65	16.59	0.03	598	4.24					273	79.65	565	1,113			35.69	1,005	110	323	294	1.67	573	1,113			35.69	122	1,005	110

Material inputs																								Material outputs																			
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process / cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	kg/unit	Nm3/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	kg/unit	kg/unit
																	1,684	932																	68.00	1,684			1,367
816		0.24	294	66.75	10.89							141					225	750		71.02								294	1,000						6.51	225			1,049
177	298		1,131	13.27				0.25				5.23			22.91		821	1,666		1.71				273			10.55	97.63		1,000					142	821			1,154
8.01						899	17.75	53.18	106				61.77		52.90		800		17.40	14.06					1,000										5.00	800			77.34
							16.32	352	702				50.32	2.54	41.71		1,000	170	54.01	3.49					125		165				1,000							1,000			251
										1,026								14.45														1,000			16.84	8.80				18.33
										1,111								305														1,000			102	8.80				386
											1,097							322															1,000		81.99	15.00				452
								0.74			1,146							810															1,000		131	15.00				1,224
927	227	0.23	1,144	74.35	10.48	728	17.89	119	237	1,024	1,164	139	60.85	0.55	69.26		2,182	3,649	25.73	81.79				208	101	35.55	8.03	357	962	762	1,025	998	1,047		119	162	2,182			5,184

Table A-51: Energy and material flow table for the UK iron and steel sector: 2007 baseline, process specific, raw data units

Standard units - 2007 sector baseline	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	m3/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	Nm3/unit	Nm3/unit	Nm3/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	Nm3/unit	Nm3/unit	Nm3/unit	kg/unit	kg/unit	kg/unit
Coke oven	Dry coke	kt	4,077	1,383												161	193				54.51	7.87	12.59	1,039	5.91	378					36.68		
Sinter plant	Sinter	kt	13,851					0.48							47.36	2.11					0.20	10.48	16.77										
Blast furnace	Hot metal	kt	10,960	113		18.35		5.49						357	44.74	16.07	448				72.61	16.80	26.89				1,639					0.64	9.29
Basic oxygen furnace	Liquid steel	kt	11,653				0.01									4.31					3.57	16.33	26.14							21.24			
Electric arc furnace	Liquid steel	kt	3,100		3.02		0.01	4.58	0.03					7.39							2.35		4.25										
Continuous caster	Semi-finished steel	kt	14,188					1.03								0.23					0.12	2.97	6.68										
Ingot caster	Semi-finished steel	kt	171					23.23													4.65		89.71										
Hot rolling mill	Hot-rolled steel	kt	10,424					33.39								4.23	14.82			13.41	4.48	27.80	70.20									0.17	
Downstream and other	Finished steel	kt	4,646																														
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	478	0.65	16.59	0.03	50.02	0.14					273	79.65	106	1,248			17.20	281	110	323	294	1.67	107	1,248			17.20	10.39	29.01	110

Table A-52: Energy and material flow table for the UK iron and steel sector: 2007 baseline, process specific, standard data units

NCV - 2007 sector baseline	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Coke oven	Dry coke	kt	4,077	159												11.37	2.53				2.86	0.12	0.18	120	0.68	26.71					5.98		
Sinter plant	Sinter	kt	13,851					0.26							18.52	0.51					0.04	0.52	0.84										
Blast furnace	Hot metal	kt	10,960	35.11		8.23		2.33						110	13.84	3.05	15.77				10.26	0.66	1.06				57.67					0.87	0.37
Basic oxygen furnace	Liquid steel	kt	11,653				0.01									0.87					0.54	0.69	1.10							1.85			
Electric arc furnace	Liquid steel	kt	3,100		0.26		0.00	0.55	0.01					0.65							0.09		4.74										
Continuous caster	Semi-finished steel	kt	14,188					0.56								0.06					0.02	0.15	0.34										
Ingot caster	Semi-finished steel	kt	171					0.15													0.01		0.06										
Hot rolling mill	Hot-rolled steel	kt	10,424					13.49								0.76	0.50			1.04	0.60	1.04	2.63									0.22	
Downstream and other	Finished steel	kt	4,646			0.25	0.01	8.23	0.20							0.74	2.07			0.81	1.97	2.53	5.80									0.22	
Power plant and Boiler						1.28		2.33								7.54	32.77				31.98											50.76	5.34
Losses/flaring																1.44	4.04				3.71												
Sector	Crude steel	kt	14,392	194	0.26	9.76	0.02	27.90	0.20					111	32.36	26.34	57.67			1.85	52.08	5.71	16.75	120	0.68	26.71	57.67			1.85	5.98	52.08	5.71

Summary	Total			SEC			Primary	SECp
Process/system/site description	Input	Output	Net	Input	Output	Net	Net	Net
Unit	PJ	PJ	PJ	GJ/t	GJ/t	GJ/t	PJ	GJ/t
Coke oven	176	153	23.44	43.27	37.52	5.75	23.73	5.82
Sinter plant	20.68		20.68	1.49		1.49	21.96	1.59
Blast furnace	201	58.91	142	18.31	5.37	12.94	143	13.08
Basic oxygen furnace	3.20	1.85	1.35	0.27	0.16	0.12	3.03	0.26
Electric arc furnace	6.31		6.31	2.04		2.04	13.61	4.39
Continuous caster	1.14		1.14	0.08		0.08	1.66	0.12
Ingot caster	0.22		0.22	1.28		1.28	0.30	1.78
Hot rolling mill	20.07	0.22	19.85	1.93	0.02	1.90	23.90	2.29
Downstream and other	22.60	0.22	22.38				31.31	
Power plant and Boiler	75.89	56.11	19.79				19.79	
Losses/flaring	9.19		9.19				9.19	
Sector	536	270	266	37.27	18.78	18.49	292	20.28

Table A-53: Energy flow table for the UK iron and steel sector: 2007 baseline; enthalpy of combustion, thermal enthalpy of steam, and electrical energy; NCV of fuels; SI units

GCV - 2007 sector baseline	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Coke oven	Dry coke	kt	4,077	168												12.63	2.53				2.86	0.12	0.18	126	0.72	29.68					6.30		
Sinter plant	Sinter	kt	13,851					0.29							19.49	0.56					0.04	0.52	0.84										
Blast furnace	Hot metal	kt	10,960	36.96		8.66		2.59						116	14.57	3.39	15.77				10.26	0.66	1.06				57.67					0.87	0.37
Basic oxygen furnace	Liquid steel	kt	11,653				0.01									0.97					0.54	0.69	1.10							1.85			
Electric arc furnace	Liquid steel	kt	3,100		0.28		0.00	0.61	0.01					0.68							0.09		4.74										
Continuous caster	Semi-finished steel	kt	14,188					0.63								0.06					0.02	0.15	0.34										
Ingot caster	Semi-finished steel	kt	171					0.17													0.01		0.06										
Hot rolling mill	Hot-rolled steel	kt	10,424					14.99								0.85	0.50			1.04	0.60	1.04	2.63									0.22	
Downstream and other	Finished steel	kt	4,646			0.27	0.01	9.14	0.21							0.82	2.07			0.81	1.97	2.53	5.80									0.22	
Power plant and Boiler						1.35		2.59								8.37	32.77				31.98											50.76	5.34
Losses/flaring																1.60	4.04				3.71												
Sector	Crude steel	kt	14,392	205	0.28	10.28	0.02	31.00	0.22					117	34.06	29.26	57.67			1.85	52.08	5.71	16.75	126	0.72	29.68	57.67			1.85	6.30	52.08	5.71

Summary	Total			SEC			Primary	SECp
Process/system/site description	Input	Output	Net	Input	Output	Net	Net	Net
Unit	PJ	PJ	PJ	GJ/t	GJ/t	GJ/t	PJ	GJ/t
Coke oven	186	163	23.48	45.64	39.88	5.76	23.77	5.83
Sinter plant	21.74		21.74	1.57		1.57	23.02	1.66
Blast furnace	210	58.91	151	19.17	5.37	13.80	153	13.94
Basic oxygen furnace	3.29	1.85	1.44	0.28	0.16	0.12	3.13	0.27
Electric arc furnace	6.42		6.42	2.07		2.07	13.72	4.42
Continuous caster	1.20		1.20	0.08		0.08	1.73	0.12
Ingot caster	0.24		0.24	1.38		1.38	0.32	1.88
Hot rolling mill	21.65	0.22	21.43	2.08	0.02	2.06	25.49	2.45
Downstream and other	23.63	0.22	23.41				32.33	
Power plant and Boiler	77.06	56.11	20.95				20.95	
Losses/flaring	9.35		9.35				9.35	
Sector	561	280	281	38.96	19.45	19.51	307	21.31

Table A-54: Energy flow table for the UK iron and steel sector: 2007 baseline; enthalpy of combustion, thermal enthalpy of steam, and electrical energy; GCV of fuels; SI units

GCV - 2007 sector baseline - ktoe	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Coke oven	Dry coke	kt	4,077	4,006												302	60.41				68.43	2.76	4.41	3,007	17.10	709					150		
Sinter plant	Sinter	kt	13,851					6.84							466	13.44					0.85	12.48	19.98										
Blast furnace	Hot metal	kt	10,960	883		207		61.82						2,775	348	80.98	377				245	15.83	25.34				1,377					20.88	8.76
Basic oxygen furnace	Liquid steel	kt	11,653				0.16									23.12					12.81	16.36	26.19							44.17			
Electric arc furnace	Liquid steel	kt	3,100		6.65		0.04	14.60	0.24					16.27							2.25		1.13										
Continuous caster	Semi-finished steel	kt	14,188					14.96								1.50					0.53	3.63	8.15										
Ingot caster	Semi-finished steel	kt	171					4.08													0.25		1.32										
Hot rolling mill	Hot-rolled steel	kt	10,424					358								20.26	11.84			24.94	14.38	24.92	62.93									5.24	
Downstream and other	Finished steel	kt	4,646			6.37	0.34	218	5.01							19.66	49.49			19.23	46.96	60.40	139									5.30	
Power plant and Boiler						32.24		61.74								200	783				764											1,212	128
Losses/flaring																38.30	96.41				88.51												
Sector	Crude steel	kt	14,392	4,889	6.65	245	0.53	740	5.25					2,791	814	699	1,377			44.17	1,244	136	400	3,007	17.10	709	1,377			44.17	150	1,244	136

Summary	Total			Primary
Process/system/site description	Input	Output	Net	Net
Unit	ktoe	ktoe	ktoe	ktoe
Coke oven	4,444	3,883	561	568
Sinter plant	519		519	550
Blast furnace	5,018	1,407	3,611	3,650
Basic oxygen furnace	78.63	44.17	34.47	74.75
Electric arc furnace	153		153	328
Continuous caster	28.77		28.77	41.31
Ingot caster	5.65		5.65	7.68
Hot rolling mill	517	5.24	512	609
Downstream and other	564	5.30	559	772
Power plant and Boiler	1,840	1,340	500	500
Losses/flaring	223		223	223
Sector	13,393	6,685	6,708	7,324

Table A-55: Energy flow table for the UK iron and steel sector: 2007 baseline; enthalpy of combustion, thermal enthalpy of steam, electrical energy; GCV of fuels; ktoe

CO_2 - 2007 sector baseline	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				$ktCO_2$	$ktCO_2$	$ktCO_2$

GhG - 2007 sector baseline	Main output			Energy inputs																		Energy outputs										
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				$ktCO_2e$	$ktCO_2e$	$ktCO_2e$

Raw data units - 2007u baseline sector	Main output			Energy inputs																				Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,509	703				796	32.08	51.34	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	145	232										
Blast furnace	Hot metal	kt	10,960	1,644				719						3,800	490	942	4,379				2,849	184	295				16,018					243	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	190	305							1,123		216	
Electric arc furnace	Liquid steel	kt	3,100		9.37		0.04	170	2.77					22.92							26.12		1,318										
Continuous caster	Semi-finished steel	kt	14,188					174								17.44					6.13	42.17	94.81										
Ingot caster	Semi-finished steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	10,424					3,553								236	138			899	167	290	732									60.93	
Downstream and other						6.20	0.31	2,539	58.23							229	576			224	546	702	1,611									61.65	
Power plant and Boiler								536								2,326	9,102				8,844											13,844	1,484
Losses/flaring																445	1,121				1,029												
Sector	Crude steel	kt	14,392	7,282	9.37	6.20	0.50	7,818	61.00					3,823	1,146	8,129	16,018			1,123	14,425	1,586	4,654	4,237	24.09	8,244	16,018			1,123	1,749	14,425	1,586

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Raw data units - 2007u baseline sector	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kg/unit	kg/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit
Coke oven	Dry coke	kt	4,077	1,383												861	172				195	7.87	12.59	1,039	5.91	2,022					429		
Sinter plant	Sinter	kt	13,851					5.74							47.36	11.29					0.71	10.48	16.77										
Blast furnace	Hot metal	kt	10,960	150				65.60						347	44.74	85.93	400				260	16.80	26.89				1,462					22.15	9.29
Basic oxygen furnace	Liquid steel	kt	11,653				0.01									23.07					12.78	16.33	26.14							96.36		18.56	
Electric arc furnace	Liquid steel	kt	3,100		3.02		0.01	54.76	0.89					7.39							8.42		425										
Continuous caster	Semi-finished steel	kt	14,188					12.26								1.23					0.43	2.97	6.68										
Ingot caster	Semi-finished steel	kt	171					278													16.67		89.71										
Hot rolling mill	Hot-rolled steel	kt	10,424					341								22.60	13.21			86.26	16.04	27.79	70.19									5.85	
Downstream and other																																	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	506	0.65	0.43	0.03	543	4.24					266	79.65	565	1,113			78.02	1,002	110	323	294	1.67	573	1,113			78.02	122	1,002	110

Material inputs																											Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	kg/unit	Nm3/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	kg/unit	kg/unit
																	1,684	932																		68.00	1,684				1,367
816		0.24	294	66.75	10.89							141					225	750		71.02								294	1,000							6.51	225				1,049
177	298		1,131	13.27				0.25				5.23			37.50		821	1,666		1.71				273			10.55	97.63		1,000						142	821				1,154
8.01						899	17.75	53.18	106				61.77		52.90		800		17.40	14.06					125						1,000						5.00	800				77.34
							16.32	352	702				50.32	2.54	41.71		1,000	170	54.01	3.49							165				1,000							1,000				251
										1,026								14.45														1,000			16.84	8.80				18.33
										1,111								305														1,000			102	8.80				386
											1,097							322															1,000		81.99	15.00				452
927	227	0.23	1,144	74.35	10.48	728	17.89	119	237	1,024	1,164	139	60.85	0.55	80.37		2,182	3,649	25.73	81.79				208	101	35.55	8.03	357	962	762	1,025	998	1,047		119	162	2,182			5,184

Table A-59: Energy and material flow table for the UK iron and steel sector: 2007u baseline, process specific, raw data units

Raw data units - 2010 sector	Main output			Energy inputs																				Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,610	5,104												3,178	732				705	33.38	49.79	3,782	30.65	7,689					1,608		
Sinter plant	Sinter	kt	9,447					54.27							409	107					6.73	103	154										
Blast furnace	Hot metal	kt	7,233	974		4.20		641						2,541	384	374	2,943				1,880	119	178				10,906					160	11.20
Basic oxygen furnace	Liquid steel	kt	7,511				0.09									168					95.99	128	191							331			
Electric arc furnace	Liquid steel	kt	2,440				0.03	130	2.11					7.05							20.56		1,037										
Continuous caster	Semi-finished steel	kt	9,553					117								11.74					4.12	28.37	63.87										
Ingot caster	Semi-finished steel	kt	133					37.00													2.22		11.95										
Hot rolling mill	Hot-rolled steel	kt	8,415					3,430								130	101			234	135	243	582									49.19	
Downstream and other							0.28	1,829	21.89							386	390			96.97	483	555	1,278									52.94	
Power plant and Boiler						10.10		743								2,635	5,445				7,112											10,988	1,199
Losses/flaring																617	1,296				803												
Sector	Crude steel	kt	9,708	6,078		14.30	0.40	6,982	24.00					2,548	793	7,608	10,906				11,248	1,210	3,545	3,782	30.65	7,689	10,906			331	1,608	11,250	1,210

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Raw data units - 2010 sector	Main output			Energy inputs																		Energy outputs										
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kg/unit	kg/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kg/unit	kg/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit	kWh/unit
Coke oven	Dry coke	kt	3,610	1,414											43.28	880	203				195	9.25	13.79	1,048	8.49	2,130					445		
Sinter plant	Sinter	kt	9,447					5.74								11.29					0.71	10.94	16.31										
Blast furnace	Hot metal	kt	7,233	135		0.58		88.66						351	53.14	51.77	407				260	16.45	24.54				1,508					22.15	1.55
Basic oxygen furnace	Liquid steel	kt	7,511				0.01									22.39					12.78	17.04	25.42								44.08		
Electric arc furnace	Liquid steel	kt	2,440				0.01	53.14	0.87					2.89							8.42		425										
Continuous caster	Semi-finished steel	kt	9,553					12.26								1.23					0.43	2.97	6.69										
Ingot caster	Semi-finished steel	kt	133					278													16.67		89.71										
Hot rolling mill	Hot-rolled steel	kt	8,415					408								15.41	12.06			27.82	16.05	28.89	69.12									5.85	
Downstream and other																																	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	9,708	626		1.47	0.04	719	2.47					262	81.71	784	1,123			34.10	1,159	125	365	390	3.16	792	1,123			34.10	166	1,159	125

Material inputs																											Material outputs																			
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	Nm3/unit	kg/unit	Nm3/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	kg/unit	Nm3/unit	kg/unit	kg/unit
																	1,697	979																		68.00	1,697				1,468
752			294	66.75	10.89							113					225	687		71.02								294	1,000							5.95	225				955
177	298		1,169	13.27				0.25				5.23			22.91		821	1,670		1.71				273			10.55	100		1,000						146	821				1,168
4.65						924	14.39	50.35	105				65.74		53.26		800		17.71	6.31					125						1,000						5.00	800				77.34
							16.20	339	705				49.24	2.54	36.32		1,000	88.03	40.98	2.50							165				1,000							1,000				146
										1,026								14.45														1,000			16.84	8.80				18.33
										1,111								305														1,000			102	8.80				386
											1,058							324															1,000		43.45	15.00				453
868	222		1,157	74.85	10.60	715	15.20	125	258	1,025	1,403	114	63.24	0.64	67.40		2,332	3,838	24.00	75.90				204	96.71	41.48	7.86	361	973	745	1,025	998	1,278		124	172	2,332			5,448

Table A-61: Energy and material flow table for the UK iron and steel sector: 2010, process specific, raw data units

1, 2	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast fumace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,509	703				796	32.08	51.34	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	145	232										
Blast fumace	Hot metal	kt	10,960	1,644				719						3,800	490	942	4,379				2,849	184	295				16,018					243	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	190	305							1,123		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	42.17	67.52										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,275								236	138				123	290	464									44.96	
Boiler	Steam	GWh	11,517					316								2,326	9,102				1,781											11,255	
Condensor turbine	Electricity	GWh	1,884																		5,021											609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	702	1,124									48.68	
Losses/flaring																445	1,121				1,029												
Int.wks (Base)	Crude steel	kt	11,362	7,282		4.89	0.40	5,531	58.23					3,800	1,146	8,129	16,018			1,123	14,206	1,586	2,539	4,237	24.09	8,244	16,018			1,123	1,749	14,206	1,586
Electric arc furnace	Liquid steel	kt	3,100		9.37		0.04	170	2.77					22.92							26.12		1,318										
Continuous caster	SF steel	kt	2,827					38.13													1.22		27.28										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	2,733					1,278													43.85		268									15.98	
Boiler	Steam	GWh	185					219													30.08											190	
Downstream and other	Finished steel	kt				1.30	0.07	534													115		487									12.97	
EAF wks (Base)	Crude steel	kt	3,028		9.37	1.30	0.10	2,287	2.77					22.92							219		2,115									219	
Sector (Base)	Crude steel	kt	14,390	7,282	9.37	6.20	0.50	7,818	61.00					3,823	1,146	8,129	16,018			1,123	14,425	1,586	4,654	4,237	24.09	8,244	16,018			1,123	1,749	14,425	1,586

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
																	6,864	3,802																	277	6,864				5,575
11,300		3.27	4,071	925	151							1,949					3,117	10,389		984							4,071	13,851							90.22	3,117				14,536
1,944	3,269		12,400	145				2.71				57.27			411		8,998	18,263		18.76				2,994			116	1,070		10,960					1,556	8,998				12,647
93.35						10,471	207	620	1,235				720		616		9,323		203	164						1,457					11,653					58.27	9,323				901
										11,653								163													11,362				191	99.98				203
											8,436							2,563														7,690		631	115				3,676
																		10,605																						25,921
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027		28,301	45,785	203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822	2,197	28,301			63,460
							50.59	1,093	2,178				156	7.87	129		3,100	529	167	10.81						512					3,100						3,100			778
										2,899								41.83													2,827			47.60	24.87				52.97
										190								52.10													171			17.50	1.50				65.98
											2,998							963														2,733		224	40.99				1,247
																		256																						324
										11.40																														
							50.59	1,093	2,178	3,100	2,998		156	7.87	129		3,100	1,842	167	10.81						512					3,100	2,998	2,733		289	67.37	3,100			2,468
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,715	3,412	14,754	11,433	2,006	876	7.87	1,157		31,402	47,627	370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	14,359	10,423		1,111	2,265	31,402			65,928

Table A-62: Energy and material flow table for the UK iron and steel sector: site 1 - Int.wks (Base); site 2 - EAF wks (Base) [2007u]

1p, 2p	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking coal	Coal	Fuel oil	Gas and Diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Steam (internally produce	Electricity (autogenerated)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Benzole and Tars	Steam (internally produced)	Electricity (autogenerated)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3553.56	4,914												3,058	612				694	44.81	27.89	3,799	21.00	7,185					1,525	1,420	
Sinter plant	Sinter	kt	13851.2					79.57							593	156					9.87	233	145									654	
Blast furnace	Hot metal	kt	10959.8	2,192				236						3,173	490	704	3,273			363	2,849	295	184				16,018					1,066	102
Basic oxygen furnace	Liquid steel	kt	11653.1				0.15									269					149	305	190							2,266		407	
Thin slab caster	Hot-rolled steel	kt	2563.32					158														109	67.85										
Continuous caster	SF steel	kt	8549.86					102								13.12					3.69	50.88	31.67										
Hot rolling mill	Hot-rolled steel	kt	5126.63					575								157	901			842	82.26	310	193									29.97	
Boiler	Steam	GWh	9507.16					501								2,205	9,084			451	1,694											11,201	
Condensor turbine	Electricity	GWh	1883.71																		8,517											1,032	2,163
Back-pressure turbine	Steam and electricity	GWh	1999.29																		2,006											1,785	208
Downstream and other	Finished steel	kt	4646.23			4.89	0.25	1,003	58.23							229	1,027			451	431	1,126	701									48.68	
Losses/flaring																394	1,121			159	1,209												
Int.wks (TP)	Crude steel	kt	11361.8	7,106		4.89	0.40	2,655	58.23					3,173	1,083	7,185	16,018			2,266	17,644	2,473	1,539	3,799	21.00	7,185	16,018			2,266	1,525	17,644	2,473
Electric arc furnace	Liquid steel	kt	3100.48		9.37		0.04	170	2.77					22.92							26.12		1,101										
Thin slab caster	Hot-rolled steel	kt	910.853					56.23															62.85										
Continuous caster	SF steel	kt	1827.4					24.65													0.79		17.64										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	1821.71					852													29.23		179									10.65	
Boiler	Steam	GWh	184.914					219													28.25											179	
Downstream and other						1.30	0.07	534													115		487									12.97	
EAF wks (TP)	Crude steel	kt	3027.9		9.37	1.30	0.10	1,904	2.77					22.92							202		1,862									202	
Sector (TP)	Crude steel	kt	14389.7	7,106	9.37	6.20	0.50	4,559	61.00					3,196	1,083	7,185	16,018			2,266	17,846	2,473	3,401	3,799	21.00	7,185	16,018			2,266	1,525	17,846	2,473

| Material inputs | | | | | | | | | | | | | | | | | | |

1p, 2p2	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking coal	Coal	Fuel oil	Gas and Diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Steam (internally produced)	Electricity (autogenerated)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Benzole and Tars	Steam (internally produced)	Electricity (autogenerated)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,554	4,914												3,058	612				694	44.81	27.89	3,799	21.00	7,185					1,525	1,420	
Sinter plant	Sinter	kt	13,851					79.57							593	156					9.87	233	145									654	
Blast furnace	Hot metal	kt	10,960	2,192				236						3,173	490	704	3,273			363	2,849	295	184				16,018					1,066	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	305	190							2,266		407	
Thin slab caster	Hot-rolled steel	kt	2,563					158														109	67.85										
Continuous caster	SF steel	kt	8,550					102								13.12					3.69	50.88	31.67										
Hot rolling mill	Hot-rolled steel	kt	5,127					575								157	901			842	82.26	310	193									29.97	
Boiler	Steam	GWh	9,507					501								2,205	9,084			451	1,694											11,201	
Condensor turbine	Electricity	GWh	1,884																		8,517											1,032	2,163
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,006											1,785	208
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,003	58.23							229	1,027			451	431	1,126	701									48.68	
Losses/flaring																394	1,121			159	1,209												
Int.wks (TP)	Crude steel	kt	11,362	7,106		4.89	0.40	2,655	58.23					3,173	1,083	7,185	16,018			2,266	17,644	2,473	1,539	3,799	21.00	7,185	16,018			2,266	1,525	17,644	2,473
Electric arc furnace	Liquid steel	kt	3100.48		9.365		0.03765	166.872	2.76836					22.923							26.1186		868.1347										
Thin slab caster	Hot-rolled steel	kt	910.853					56.2255															62.84887										
Continuous caster	SF steel	kt	1827.4					24.6521													0.78873		17.63961										
Ingot caster	SF steel	kt	171					47.5													2.85		15.34025										
Hot rolling mill	Hot-rolled steel	kt	1821.71					851.689													29.2307		178.5365									10.6504	
Boiler	Steam	GWh	184.914					219.469													28.2509											178.529	
Downstream and other						1.30335	0.06612	534.263													114.911		487.2094									12.9709	
EAF wks (TP2)	Crude steel	kt	3027.9		9.365	1.30335	0.10377	1900.67	2.76836					22.923							202.15		1629.709									202.15	
Sector (TP2)	Crude steel	kt	14,390	7,106	9.37	6.20	0.50	4,556	61.00					3,196	1,083	7,185	16,018			2,266	17,846	2,473	3,169	3,799	21.00	7,185	16,018			2,266	1,525	17,846	2,473

Material inputs																							Material outputs															
Iron ore	Iron ore Pellets	Manganese ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (net receipts	Liquid steel	SF steel	Limestone & Dolomite	Lime and calcined dolomite	Electrodes	O2	N2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MDEA make-up	Sodium hydroxide	Blast furnace slag	BOF slag	EAF slag	Blast furnace flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O2	CO2 (captured)	Other flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653									
										2,884																							2,563		321				
										8,769																						8,550		144				
											6,348																						5,787		474				
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	6,348	2,006	720		1,027				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	8,550	8,350		939				
							50.59	1092.89	2177.71				156.02	2.79043	129.312				167.467	10.809						511.579					3100.48									
										1036.22																							910.853		125.369				
										1874.26																									30.7753				
										190																									17.4952				
											1998.4																						1821.71		149.371				
							50.59	1092.89	2177.71	3100.48	1998.4		156.02	2.79043	129.312				167.467	10.809						511.579					3100.48	1998.4	2732.56		323.01				
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,715	3,412	14,754	8,346	2,006	876	2.79	1,157				370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	10,548	11,083		1,262				

Table A-64: Energy and material flow table for the UK iron and steel sector: site 1p - Int.wks (TP2); site 2p2 - EAF wks (TP2)

1b, 2b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,314	4,583												1,825	329				545	103		3,440	24.09	6,701					1,422	1,417	
Sinter plant	Sinter	kt	13,851												537	72.68						375										654	
Blast furnace	Hot metal	kt	10,960	2,404				581						3,456		761	3,183				1,151	664					15,222					1,066	548
Basic oxygen furnace	Liquid steel	kt	11,653													619						303								2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563													158						177											
Continuous caster	SF steel	kt	8,550					79.17														65.83											
Hot rolling mill	Hot-rolled steel	kt	5,127					488								445	109			219	47.45	384	6.63									68.36	
Boiler	Steam	GWh	12,728													2,225	9,960			1,118	1,933											12,728	
Condensor turbine	Electricity	GWh	2,832																		12,249											1,485	3,111
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,006											1,785	208
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,003	58.23							229	576			902	431	1,796	31.02									48.68	
Losses/flaring																367	1,066			169	1,433												
Int.wks (BAT)	Crude steel	kt	11,362	6,988		4.89	0.25	2,150	58.23					3,456	537	6,701	15,222			2,408	19,796	3,867	37.65	3,440	24.09	6,701	15,222			2,408	1,422	19,796	3,867
Electric arc furnace	Liquid steel	kt	3,100		39.95			167															868										
Thin slab caster	Hot-rolled steel	kt	911					56.23															62.85										
Continuous caster	SF steel	kt	1,827					16.92															14.07										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	1,822					461													16.86		139									24.29	
Boiler	Steam	GWh	185					120													18.30											116	
Downstream and other						1.30	0.07	534													115		487									12.97	
EAF wks (BAT)	Crude steel	kt	3,028		39.95	1.30	0.07	1,403													153		1,586									153	
Sector (BAT)	Crude steel	kt	14,390	6,988	39.95	6.20	0.31	3,553	58.23					3,456	537	6,701	15,222			2,408	19,948	3,867	1,624	3,440	24.09	6,701	15,222			2,408	1,422	19,948	3,867

	Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851												
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960										
93.35						10,471	207	620	1,235				720		616				203	164					1,457					11,653											
										2,884																						2,563		321						
										8,769																						8,550		144						
											5,624																					5,127		420						
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	5,624	2,006	720		1,027				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	8,550	7,690		885					
							50.59	1,093	2,178				156	2.79	77.51				167	10.81						512					3,100										
										1,036																						911		125						
										1,874																					1,827		30.78						
										190																					171		17.50						
											1,998																					1,822		149						
							50.59	1,093	2,178	3,100	1,998		156	2.79	77.51				167	10.81						512					3,100	1,998	2,733		323						
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,715	3,412	14,754	7,622	2,006	876	2.79	1,105				370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	10,548	10,423		1,208					

Table A-65: Energy and material flow table for the UK iron and steel sector: site 1b - Int.wks (BAT); site 2b - EAF wks (BAT)

1b2, 2b2	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking coal	Coal	Fuel oil	Gas and Diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Steam (internally produce	Electricity (autogenerated)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas (DRI site)	Basic oxygen furnace gas	Benzole and Tars	Steam (internally produced)	Electricity (autogenerated)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,294	660				328	76.86	49.79	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851												677	209						252	163									619	
Blast furnace	Hot metal	kt	10,960	989		354		618						4,204		809	3,386				1,224	403	261				14,309						384
Basic oxygen furnace	Liquid steel	kt	11,653													619						184	119							2,408		544	
Continuous caster	SF steel	kt	11,362					105														53.10	34.39										
Hot rolling mill	Hot-rolled steel	kt	7,690					630								1,335	401			501	71.17	368	239									74.76	
Boiler	Steam	GWh	11,517													1,188	8,285			837	1,564											9,975	
Condensor turbine	Electricity	GWh	1,884																		7,297											885	1,853
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,003	58.23							229	576			902	431	1,109	718									48.68	
Losses/flaring																445	1,002			169	1,009												
Int.wks (BPT)	Crude steel	kt	11,362	6,627		359	0.25	2,356	58.23					4,204	677	8,129	14,309			2,408	13,936	2,446	1,584	4,237	24.09	8,244	14,309			2,408	1,749	13,936	2,446
Electric arc furnace	Liquid steel	kt	3,100		39.95			148															1,163										
Continuous caster	SF steel	kt	2,827					26.17															21.76										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	2,733					1,054													25.29		216									26.57	
Boiler	Steam	GWh	185					128													19.46											123	
Downstream and other						1.30	0.07	534													115		487									12.97	
EAF.wks (BPT)	Crude steel	kt	3,028		39.95	1.30	0.07	1,938													163		1,903									163	
Sector (BPT)	Crude steel	kt	14,390	6,627	39.95	360	0.31	4,294	58.23					4,204	677	8,129	14,309			2,408	14,099	2,446	3,487	4,237	24.09	8,244	14,309			2,408	1,749	14,099	2,446

Material inputs																								Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851											
1,944	3,269		12,400	145				2.71				57.27			384					18.76				2,994			116	1,070		10,960										
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653										
										11,653																						11,362		191						
											8,436																						7,690	631						
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		990				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822					
							50.59	1,093	2,178				156	7.87	133				167	10.81						512						3,100										
										2,899																						2,827		47.60						
										190																						171		17.50						
											2,998																						2,733	224						
							50.59	1,093	2,178	3,089	2,998		156	7.87	133				167	10.81						512						3,100	2,998	2,733		289					
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,715	3,412	14,742	11,433	2,006	876	7.87	1,122				370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	14,359	10,423		1,111					

Table A-66: Energy and material flow table for the UK iron and steel sector: site 1b2 - Int.wks (BPT); site 2b2 - EAF wks (BPT)

1s	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,162	4,373												2,722	545				617	24.88	39.82	3,286	18.69	6,394					1,357		
Sinter plant	Sinter	kt	10,743					61.71							509	121					7.65	113	180										
Blast furnace	Hot metal	kt	8,500	1,275				558						2,947	380	730	3,397				2,210	143	229				12,424				188	79.00
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	198	297							926	216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	43.81	65.88									
Hot rolling mill	Hot-rolled steel	kt	7,690					2,493								236	138			703	123	301	453								44.96	
Boiler	Steam	GWh	10,254					2,236								1,720	6,899				1,623										10,254	
Condensor turbine	Electricity	GWh	1,884																		5,021										609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	730	1,097								48.68	
Losses/flaring																350	870				953											
Int.wks max scrap	Crude steel	kt	11,362	5,648		4.89	0.40	7,490	58.23					2,947	889	6,394	12,424			926	13,151	1,552	2,361	3,286	18.69	6,394	12,424			926	1,357	13,151	1,563

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

1bs	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,570	3,555												1,699					423	79.85		2,668	18.69	5,197					1,103	1,099	
Sinter plant	Sinter	kt	10,743												416	56.37						291										507	
Blast furnace	Hot metal	kt	8,500	1,865				450						2,680		590	2,469				893	515					11,806					826	425
Basic oxygen furnace	Liquid steel	kt	11,653													619						396	16.76							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														170	7.18										
Continuous caster	SF steel	kt	8,550					59.57														47.53	2.01										
Hot rolling mill	Hot-rolled steel	kt	5,127					216								162	292			146	31.63	250	10.57									45.57	
Boiler	Steam	GWh	12,728					2,534								1,614	7,643			799	1,889											11,938	
Condensor turbine	Electricity	GWh	2,832																		11,152											1,352	2,832
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,006											1,785	208
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,003	58.23							229	576			902	431	1,752	74.15									48.68	
Losses/flaring																285	826			139	1,321												
Int.wks max scrap (BAT)	Crude steel	kt	11,362	5,419		4.89	0.25	4,421	58.23					2,680	416	5,254	11,806			1,987	18,145	3,501	111	2,668	18.69	5,197	11,806			1,987	1,103	18,145	3,465

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743											
1,508	2,536		9,617	113				2.10				44.41			425					14.55				2,322			89.65	830		8,500										
93.35						8,012	207	620	3,694				720		606				203	164					1,457					11,653											
										2,884																						2,563		321						
										8,769																								108						
											3,749																						3,418		280						
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	3,749	1,556	720		1,031				203	941				2,322	1,457		89.65	3,987	10,743	8,500	11,653	8,550	5,981		709					

Table A-68: Energy and material flow table for the UK iron and steel sector: site 1bs - Int.wks max scrap (BAT)

3g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953									
Thin slab caster	Hot-rolled steel	kt	2,563					158																								
Continuous caster	SF steel	kt	8,550					63.33															107									
Hot rolling mill	Hot-rolled steel	kt	5,127					2,184															441									
Boiler	Steam	GWh	571					594													90.38										571	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,033	58.23												431		1,827								48.68	
EAF gnf.wks	Crude steel	kt	11,362		140	4.89	0.25	6,589	58.23												620		7,327								620	

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
							190	620	11,673				586	29.59	486				629	40.63						1,923					11,653										
										2,884																															
										8,769																															
											5,624																					8,550									
																																5,127		497						
							190	620	11,673	11,653	5,624		586	29.59	486				629	40.63						1,923					11,653	8,550	7,690		1,037					

Table A-69: Energy and material flow table for the UK iron and steel sector: site 3g - EAF gnf.wks (BAT)

3gb	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263									
Thin slab caster	Hot-rolled steel	kt	2,563					158																								
Continuous caster	SF steel	kt	8,550					79.17															65.83									
Hot rolling mill	Hot-rolled steel	kt	5,127					1,297													47.45		391								68.36	
Boiler	Steam	GWh	571					447													68.00										430	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,033	58.23												431		1,827								48.68	
EAF gnf.wks (BAT)	Crude steel	kt	11,362		150	4.89	0.25	5,642	58.23												547		5,546								547	

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
							190	620	11,673				586	10.49	291				629	40.63						1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			144						
											5,624																					5,127		420						
							190	620	11,673	11,653	5,624		586	10.49	291				629	40.63						1,923					11,653	8,550	7,690		885					

Table A-70: Energy and material flow table for the UK iron and steel sector: site 3gb - EAF gnf.wks (BAT)

4	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,509	703				796	21.76	61.65	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	98.48	279										
Blast furnace	Hot metal	kt	10,960	1,644				719						3,800	490	942	4,379				2,849	125	354				16,018				243	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	129	366							1,123	216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	28.62	81.08									
Hot rolling mill	Hot-rolled steel	kt	7,690					2,275								236	138			899	123	197	557								44.96	
Boiler	Steam	GWh	28,777					20,058								2,441	9,102				4,554										28,777	
Condensor turbine	Electricity	GWh	1,884																		5,021										609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	477	1,350								48.68	
Losses/flaring																445	1,121				2,317											
MEA sep. equipment	CO_2	kt	15,994																		13,462	510	1,444									
Int.wks, MEA sep.	Crude steel	kt	11,362	7,282		4.89	0.40	25,273	58.23					3,800	1,146	8,244	16,018			1,123	31,728	1,586	4,493	4,237	24.09	8,244	16,018			1,123	1,749	31,728	1,586

Material inputs																								Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851											
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994				116	1,070		10,960								
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653										
										11,653																						11,362			191					
											8,436																						7,690		631					
																							15,994																	15,994	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166		15,994		2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822				15,994	

Table A-71: Energy and material flow table for the UK iron and steel sector: site 4 - Int.wks, MEA sep.

4b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,314	4,583												2,191					545	39.51	63.44	3,444	19.59	6,701					1,422	1,417	
Sinter plant	Sinter	kt	13,851					72.68							537							144	231									654	
Blast furnace	Hot metal	kt	10,960	2,404										3,456		731	3,732				1,151	255	409				15,222					1,066	548
Basic oxygen furnace	Liquid steel	kt	11,653													619						116	187							2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														67.88	109										
Continuous caster	SF steel	kt	8,550					79.17														25.27	40.57										
Hot rolling mill	Hot-rolled steel	kt	5,127					1,297																								68.36	
Boiler	Steam	GWh	21,355					8,453								2,565	9,848			2,016	3,379											21,355	
Condensor turbine	Electricity	GWh	1,884																		5,021											609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	701	1,126									48.68	
Losses/flaring																367	1,066			169	2,008												
MEA sep. equipment	CO_2	kt	15,394																		12,956	534	857										
Int.wks, MEA sep. (BAT)	Crude steel	kt	11,362	6,988		4.89	0.25	12,066	58.23					3,456	537	6,701	15,222			2,408	27,551	2,032	3,263	3,444	19.59	6,701	15,222			2,408	1,422	27,551	2,032

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653									
										2,884																							2,563		321					
										8,769																						8,550		144					
											5,624																						5,127		420					
																						15,394																	15,394	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166		15,994		2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822				15,994	

Table A-72: Energy and material flow table for the UK iron and steel sector: site 4b - Int.wks, MEA sep. (BAT)

4s	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,162	4,373												2,722	545				617	16.88	47.82	3,286	18.69	6,394					1,357		
Sinter plant	Sinter	kt	10,743					61.71							509	121					7.65	76.38	216										
Blast furnace	Hot metal	kt	8,500	1,275				558						2,947	380	730	3,397				2,210	96.88	274				12,424				188	79.00
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	142	353							926	216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	31.45	78.25									
Hot rolling mill	Hot-rolled steel	kt	7,690					2,493								236	138			703	123	216	538								44.96	
Boiler	Steam	GWh	24,041					17,860								1,720	6,899				3,804										24,041	
Condensor turbine	Electricity	GWh	1,884																		5,021										609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	524	1,303								48.68	
Losses/flaring																350	870				1,954											
MEA sep. equipment	CO_2	kt	12,599																		10,604	441	1,098									
Int.wks, max scrap, MEA sep.	Crude steel	kt	11,362	5,648		4.89	0.40	23,114	58.23					2,947	889	6,394	12,424			926	26,938	1,563	3,890	3,286	18.69	6,394	12,424			926	1,357	26,938	1,563

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743										
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690	631					
																						15,994																	12,599	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	8,436	1,556	720		935				203	941		15,994		2,322	1,457		89.65	3,987	10,743	8,500	11,653	11,362	7,690		822				12,599	

Table A-73: Energy and material flow table for the UK iron and steel sector: site 4s - Int.wks, max scrap, MEA sep.

4bs	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,570	3,555												1,699					423	30.64	49.20	2,671	15.19	5,197					1,103	1,099	
Sinter plant	Sinter	kt	10,743					56.37							416							112	179									507	
Blast furnace	Hot metal	kt	8,500	1,865										2,680		567	2,895				893	198	317				11,806					826	425
Basic oxygen furnace	Liquid steel	kt	11,653													619						122	181							1,987		544	
Thin slab caster	SF steel	kt	2,563					158														71.16	106										
Continuous caster	SF steel	kt	8,550					79.17														26.49	39.35										
Hot rolling mill	Hot-rolled steel	kt	5,127					1,297																								68.36	
Boiler	Steam	GWh	18,152					8,657								1,800	7,509			1,595	2,872											18,152	
Condensor turbine	Electricity	GWh	1,884																		5,021											609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	735	1,092									48.68	
Losses/flaring																285	826			169	1,722												
MEA sep. equipment	CO_2	kt	12,147																		10,223	441	656										
Int.wks, max scrap, MEA sep. (BAT)	Crude steel	kt	11,362	5,419		4.89	0.25	12,254	58.23					2,680	416	5,197	11,806			1,987	23,645	1,909	2,836	2,671	15.19	5,197	11,806			1,987	1,103	23,645	1,909

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743										
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653									
										2,884																						2,563		321					
										8,769																							8,550		144					
											5,624																					5,127		420					
																						12,147																12,147	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	5,624	1,556	720		925				203	941		12,147		2,322	1,457		89.65	3,987	10,743	8,500	11,653	8,550	7,690		885				12,147	

Table A-74: Energy and material flow table for the UK iron and steel sector: site 4bs - Int.wks, max scrap, MEA sep. (BAT)

5/6	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,116	4,309												2,682		537			608	17.87	45.88	3,238	18.41	6,301					1,337		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	106	272										
TGRBF	Hot metal	kt	10,960	1,833				2,474						2,917		170		23,056				107	275					28,185					
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	139	356							1,123		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	30.74	78.95										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,240								245		1,069		899	123	211	542										
Boiler	Steam	GWh	14,915					11,300								2,087		3,164			2,360										14,915		
Condensor turbine	Electricity	GWh	1,369																		5,021										609	1,369
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
ASU - low purity	O2	Mm3	411																		6.46	55.27	142										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	512	1,315								48.68		
Losses/flaring																445		359			1,273												
MDEA sep. equipment	CO2	kt	8,548																		5,580	399	1,025										
TGR-BF wks, MDEA sep.	Crude steel	kt	11,362	6,142		4.89	0.40	17,875	58.23					2,917	656	6,301		28,185		1,123	17,579	1,578	4,052	3,238	18.41	6,301		28,185		1,123	1,337	17,579	1,578

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690	631					
																																						411		
																						129,745																8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166		129,745		2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822			411	8,548	

Table A-75: Energy and material flow table for the UK iron and steel sector: site 5/6 - TGR-BF wks, MDEA sep.

5/6b	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,116	4,309												2,060					512	32.59	64.20	3,238	18.41	6,301					1,337	1,332	
Sinter plant	Sinter	kt	13,851					72.68							537							126	248									654	
TGRBF	Hot metal	kt	10,960	1,833				297						2,917		714		24,526				129	254					28,185				1,066	
Basic oxygen furnace	Liquid steel	kt	11,653													619						102	201							2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														59.55	117										
Continuous caster	SF steel	kt	8,550					79.17														22.17	43.67										
Hot rolling mill	Hot-rolled steel	kt	5,127					126								214		193		669	47.45	132	259									68.36	
Boiler	Steam	GWh	11,479					7,322								2,120		3,211			1,816											11,479	
Condensor turbine	Electricity	GWh	1,369																		6,024											730	1,530
Back-pressure turbine	Steam and electricity	GWh	4,646																		2,011											1,790	209
ASU - low purity	O2	Mm3	411																		6.46	41.49	81.74										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	899	58.23							229				1,571	431	615	1,212									48.68	
Losses/flaring																345		256		169	1,283												
MDEA sep. equipment	CO2	kt	8,548																		5,580	479	944										
TGR-BF wks, MDEA sep. (BAT)	Crude steel	kt	11,362	6,142		4.89	0.25	8,954	58.23					2,917	537	6,301		28,185		2,408	17,712	1,739	3,425	3,238	18.41	6,301		28,185		2,408	1,337	17,712	1,739

Material inputs																							Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653									
										2,884																							2,563		321					
										8,769																						8,550		144					
											5,624																						5,127		420					
																																					411			
																						129,745																	8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	5,624	2,006	720		1,017				203	1,166		129,745		2,994	1,457		116	5,141	13,851	10,960	11,653	8,550	7,690		885			411	8,548	

Table A-76: Energy and material flow table for the UK iron and steel sector: site 5/6b - TGR-BF wks, MDEA sep. (BAT)

5/6s	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,417	3,342												2,080		416			472	15.53	33.92	2,512	14.28	4,887					1,037		
Sinter plant	Sinter	kt	10,743					61.71							509	121					7.65	91.93	201										
TGRBF	Hot metal	kt	8,500	1,422				1,919						2,263		132		17,882				93.16	204					21,860					
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	155	339							926		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	34.45	75.25										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,459								245		1,069		703	123	237	517										
Boiler	Steam	GWh	13,124					10,888								1,526		2,214			2,077										13,124		
Condensor turbine	Electricity	GWh	1,369																		5,021										609	1,369
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
ASU - low purity	O2	Mm3	319																		5.01	30.21	65.99										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	574	1,253									48.68	
Losses/flaring																268		278			1,158											
MDEA sep. equipment	CO2	kt	6,630																		4,328	347	757										
TGR-BF wks, max scrap, MDEA sep.	Crude steel	kt	11,362	4,764		4.89	0.40	17,108	58.23					2,263	509	4,887		21,860		926	15,788	1,578	3,446	2,512	14.28	4,887		21,860		926	1,037	15,788	1,578

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743										
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690	631					
																																						319		
																						129,745																6,630	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	8,436	1,556	720		935				203	941		129,745		2,322	1,457		89.65	3,987	10,743	8,500	11,653	11,362	7,690		822			319	6,630	

Table A-77: Energy and material flow table for the UK iron and steel sector: site 5/6s - TGR-BF wks, max scrap, MDEA sep.

5/6bs	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,417	3,342												1,597					397	28.22	46.85	2,512	14.28	4,887					1,037	1,033	
Sinter plant	Sinter	kt	10,743					56.37							416							109	181									507	
TGRBF	Hot metal	kt	8,500	1,422				230						2,263		554		19,022				112	185					21,860				826	
Basic oxygen furnace	Liquid steel	kt	11,653													619						114	189							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														66.49	110										
Continuous caster	SF steel	kt	8,550					79.17														24.75	41.09										
Hot rolling mill	Hot-rolled steel	kt	5,127					562								214		193		277	47.45	147	244									68.36	
Boiler	Steam	GWh	10,528					7,806								1,406		2,447			1,666											10,528	
Condensor turbine	Electricity	GWh	1,369																		6,024											730	1,530
Back-pressure turbine	Steam and electricity	GWh	4,646																		2,011											1,790	209
ASU - low purity	O2	Mm3	319																		5.01	35.93	59.65										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	899	58.23							229				1,571	431	687	1,140									48.68	
Losses/flaring																268		199		139	1,166												
MDEA sep. equipment	CO2	kt	6,630																		4,328	415	689										
TGR-BF wks, max scrap, MDEA sep. (BAT	Crude steel	kt	11,362	4,764		4.89	0.25	9,791	58.23					2,263	416	4,887		21,860		1,987	16,076	1,739	2,886	2,512	14.28	4,887		21,860		1,987	1,037	16,076	1,739

Material inputs																							Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743										
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653									
										2,884																							2,563		321				
										8,769																									144				
											5,624																								420				
																																				319			
																						129,745																	6,630	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	5,624	1,556	720		925				203	941		129,745		2,322	1,457		89.65	3,987	10,743	8,500	11,653	8,550	7,690		885			319	6,630	

Table A-78: Energy and material flow table for the UK iron and steel sector: site 5/6bs - TGR-BF wks, max scrap, MDEA sep. (BAT)

5/6.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,116	4,309												2,682		537			608	15.65	48.10	3,238	18.41	6,301					1,337		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	92.64	285										
TGRBF	Hot metal	kt	10,960	1,833				2,474						2,917		170		23,056				93.87	289					28,185					
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	121	373							1,123		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	26.92	82.78										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,240								245		1,069		899	123	185	569										
Boiler	Steam	GWh	7,669					3,088								2,087		3,164			1,214											7,669	
Condensor turbine	Electricity	GWh	1,369																		5,021											609	1,369
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
ASU - low purity	O2	Mm3	411																		6.46	48.40	149										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	448	1,378									48.68	
Losses/flaring																445		359			753												
VPSA sep. equipment	CO2	kt	8,548																			545	1,677										
TGR-BF wks, VPSA sep.	Crude steel	kt	11,362	6,142		4.89	0.40	9,663	58.23					2,917	656	6,301		28,185		1,123	10,332	1,578	4,851	3,238	18.41	6,301		28,185		1,123	1,337	10,332	1,578

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690	631					
																																					411		
																																						8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822			411	8,548	

Table A-79: Energy and material flow table for the UK iron and steel sector: site 5/6.v - TGR-BF wks, VPSA sep.

5/6b.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	3,116	4,309												2,060					512	28.22	68.58	3,238	18.41	6,301					1,337	1,332	
Sinter plant	Sinter	kt	13,851					72.68							537							109	265									654	
TGRBF	Hot metal	kt	10,960	1,833				297						2,917		714		24,526				112	271					28,185				1,066	
Basic oxygen furnace	Liquid steel	kt	11,653													619						88.33	215							2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														51.56	125										
Continuous caster	SF steel	kt	8,550					79.17														19.19	46.64										
Hot rolling mill	Hot-rolled steel	kt	5,127					126								214		193		669	47.45	114	277									68.36	
Boiler	Steam	GWh	4,224													2,120		3,211			668											4,224	
Condensor turbine	Electricity	GWh	1,369																		6,022											730	1,529
Back-pressure turbine	Steam and electricity	GWh	4,646																		2,011											1,790	209
ASU - low purity	O2	Mm3	411																		6.46	35.93	87.30										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	899	58.23							229				1,571	431	533	1,294									48.68	
Losses/flaring																345		256		169	757												
VPSA sep. equipment	CO2	kt	8,548																			648	1,575										
TGR-BF wks, VPSA sep. (BAT)	Crude steel	kt	11,362	6,142		4.89	0.25	1,632	58.23					2,917	537	6,301		28,185		2,408	10,457	1,738	4,224	3,238	18.41	6,301		28,185		2,408	1,337	10,457	1,738

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653									
										2,884																							2,563		321					
										8,769																						8,550		144					
											5,624																						5,127		420					
																																					411			
																																						8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	5,624	2,006	720		1,017				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	8,550	7,690		885			411	8,548	

Table A-80: Energy and material flow table for the UK iron and steel sector: site 5/6b.v - TGR-BF wks, VPSA sep. (BAT)

5/6s.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,417	3,342												2,080		416			472	13.82	35.62	2,512	14.28	4,887					1,037		
Sinter plant	Sinter	kt	10,743					61.71							509	121					7.65	81.84	211										
TGRBF	Hot metal	kt	8,500	1,422				1,919						2,263		132		17,882				82.93	214					21,860					
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	138	357							926		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	30.67	79.03										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,459								245		1,069		703	123	211	543										
Boiler	Steam	GWh	7,481					4,492								1,526		2,214			1,184											7,481	
Condensor turbine	Electricity	GWh	1,369																		5,021											609	1,369
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
ASU - low purity	O2	Mm3	319																		5.01	26.89	69.31										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	511	1,316									48.68	
Losses/flaring																268		278			735												
VPSA sep. equipment	CO2	kt	6,630																			482	1,242										
TGR-BF wks, max scrap, VPSA sep.	Crude steel	kt	11,362	4,764		4.89	0.40	10,712	58.23					2,263	509	4,887		21,860		926	10,144	1,578	4,066	2,512	14.28	4,887		21,860		926	1,037	10,144	1,578

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743											
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690	631					
																																						319		
																																							6,630	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	8,436	1,556	720		935				203	941				2,322	1,457		89.65	3,987	10,743	8,500	11,653	11,362	7,690		822			319	6,630	

Table A-81: Energy and material flow table for the UK iron and steel sector: site 5/6s.v - TGR-BF wks, max scrap, VPSA sep.

5/6bs.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,417	3,342												1,597					397	24.89	50.19	2,512	14.28	4,887					1,037	1,033	
Sinter plant	Sinter	kt	10,743					56.37							416							96.31	194									507	
TGRBF	Hot metal	kt	8,500	1,422				230						2,263		554		19,022				98.35	198					21,860				826	
Basic oxygen furnace	Liquid steel	kt	11,653													619						100	203							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														58.63	118										
Continuous caster	SF steel	kt	8,550					79.17														21.82	44.01										
Hot rolling mill	Hot-rolled steel	kt	5,127					562								214		193		277	47.45	130	261									68.36	
Boiler	Steam	GWh	4,896					1,424								1,406		2,447			775											4,896	
Condensor turbine	Electricity	GWh	1,369																		6,024											730	1,530
Back-pressure turbine	Steam and electricity	GWh	4,646																		2,011											1,790	209
ASU - low purity	O2	Mm3	319																		5.01	31.68	63.89										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	899	58.23							229				1,571	431	606	1,221									48.68	
Losses/flaring																268		199		139	753												
VPSA sep. equipment	CO2	kt	6,630																			571	1,152										
TGR-BF wks, max scrap, VPSA sep. (BAT	Crude steel	kt	11,362	4,764		4.89	0.25	3,409	58.23					2,263	416	4,887		21,860		1,987	10,444	1,739	3,506	2,512	14.28	4,887		21,860		1,987	1,037	10,444	1,739

Material inputs																							Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
8,764		2.54	3,157	717	117							1,511								763								3,157	10,743										
1,508	2,536		9,617	113				2.10				44.41			319					14.55				2,322			89.65	830		8,500									
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653									
										2,884																							2,563		321				
										8,769																						8,550		144				
											5,624																						5,127		420				
																																				319			
																																						6,630	
10,365	2,536	2.54	12,774	830	117	8,012	207	622	3,694	11,653	5,624	1,556	720		925				203	941				2,322	1,457		89.65	3,987	10,743	8,500	11,653	8,550	7,690		885			319	6,630	

Table A-82: Energy and material flow table for the UK iron and steel sector: site 5bs.v - TGR-BF wks, max scrap, VPSA sep. (BAT)

7	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
HIsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	767									17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	495								1,123	216	
Continuous caster	SF steel	kt	11,362					153													4.90	110										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664													123	754									44.96	
Condensor turbine	Electricity	GWh	3,653					1,599																							1,744	3,653
ASU	O2	Mm3	4,693																		3,107											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23												431	1,528	299								48.68	
Losses/flaring																					1,442											
HIsarna wks	Crude steel	kt	11,362		5,806	4.89	0.40	7,558	58.23	1,390										1,123	19,888	3,653	299							1,123		19,888	3,653

Material inputs																										Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960										
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653										
										11,653																						11,362		191						
											8,436																						7,690		631						
																																					4,693			
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164				1,534	1,457		923			10,960	11,653	11,362	7,690		822			4,693		

Table A-83: Energy and material flow table for the UK iron and steel sector: site 7 - HIsarna wks

7b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	767										18,900	
Basic oxygen furnace	Liquid steel	kt	11,653					619														303								2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					79.17														65.83											
Hot rolling mill	Hot-rolled steel	kt	5,127					177												1,008	47.45	391										68.36	
Condensor turbine	Electricity	GWh	4,098					673												1,008	16,137											1,956	4,098
ASU	O2	Mm3	4,693																		3,107												
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	1,827										48.68	
Losses/flaring																				169	1,551												
Hlsarna wks (BAT)	Crude steel	kt	11,362		5,806	4.89	0.25	4,580	58.23	1,390										2,408	21,517	3,530								2,408		21,517	4,098

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960										
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653										
										2,884																						2,563		321						
										8,769																								144						
											5,624																						5,127		420						
																																						4,693		
16,084					923	10,471	207	620	1,235	11,653	5,624	1,081	720		4,683				203	164				1,534	1,457		923			10,960	11,653	8,550	7,690		885			4,693		

Table A-84: Energy and material flow table for the UK iron and steel sector: site 7b - HIsarna wks (BAT)

7s	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	410	185									13,832	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	341	154							926		216	
Continuous caster	SF steel	kt	11,362					153													4.90	75.66	34.04										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,882													123	520	234									44.96	
Condensor turbine	Electricity	GWh	2,607					1,141													10,266											1,244	2,607
ASU	O2	Mm3	3,768																		3,107												
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23												431	1,260	567									48.68	
Losses/flaring																					1,116												
Hlsarna wks, max scrap	Crude steel	kt	11,362		4,503	4.89	0.40	7,318	58.23	1,078										926	15,386	2,607	1,173							926		15,386	2,607

Material inputs																											Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716						838				3,162									1,190			716			8,500										
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653										
										11,653																						11,362		191						
											8,436																						7,690		631						
																																						3,768			
12,495					716	8,012	207	620	3,694	11,653	8,436	838	720		3,779				203	164				1,190	1,457		716			8,500	11,653	11,362	7,690		822			3,768		

Table A-85: Energy and material flow table for the UK iron and steel sector: site 7s - HIsarna wks, max scrap

7bs	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	529	65.77									14,658	
Basic oxygen furnace	Liquid steel	kt	11,653					619														269	33.49							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														157	19.55										
Continuous caster	SF steel	kt	8,550					79.17														58.56	7.28										
Hot rolling mill	Hot-rolled steel	kt	5,127					177												1,008	47.45	347	43.18									68.36	
Condensor turbine	Electricity	GWh	2,987					622												616	11,762											1,426	2,987
ASU	O2	Mm3	3,768																		3,107												
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	1,625	202									48.68	
Losses/flaring																				139	1,209												
Hlsarna wks, max scrap (BAT)	Crude steel	kt	11,362		4,503	4.89	0.25	4,529	58.23	1,078										1,987	16,745	2,987	371							1,987		16,745	2,987

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716							838			3,162									1,190			716			8,500										
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653										
										2,884																						2,563		321					
										8,769																						8,550		144					
											5,624																					5,127		420					
																																					3,768		
12,495					716	8,012	207	620	3,694	11,653	5,624	838	720		3,768				203	164				1,190	1,457		716			8,500	11,653	8,550	7,690		885			3,768		

Table A-86: Energy and material flow table for the UK iron and steel sector: site 7bs - HIsarna wks, max scrap (BAT)

8	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	199	568									17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	129	366							1,123		216	
Continuous caster	SF steel	kt	11,362					153													4.90	28.50	81.20										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664												899	123	196	558									44.96	
Condensor turbine	Electricity	GWh	2,159					945													8,503										1,031	2,159
ASU	O2	Mm3	4,693																		73.82	585	1,667										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	475	1,352									48.68	
Losses/flaring																					1,390												
MDEA sep. equipment	CO2	kt	12,649																		8,256	547	1,559										
Hlsarna wks, MDEA sep.	Crude steel	kt	11,362		5,806	4.89	0.40	6,904	58.23	1,390										1,123	19,175	2,159	6,151							1,123		19,175	2,159

Material inputs																										Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960											
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653											
										11,653																						11,362		191							
											8,436																						7,690		631						
																																						4,693			
																						172,779																	12,649	
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164		172,779		1,534	1,457		923			10,960	11,653	11,362	7,690		822			4,693	12,649	

Table A-87: Energy and material flow table for the UK iron and steel sector: site 8 - HIsarna wks, MDEA sep.

8b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	253	514									18,900	
Basic oxygen furnace	Liquid steel	kt	11,653					619														99.86	203							2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														58.30	119										
Continuous caster	SF steel	kt	8,550					79.17														21.70	44.14										
Hot rolling mill	Hot-rolled steel	kt	5,127					265												929	47.45	129	262									68.36	
Condensor turbine	Electricity	GWh	2,600					629												457	10,239											1,241	2,600
ASU	O2	Mm3	4,693																		73.82	742	1,510										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,925	58.23											853	431	602	1,225									48.68	
Losses/flaring																				169	1,511												
MDEA sep. equipment	CO2	kt	12,649																		8,256	694	1,412										
Hlsarna wks, MDEA sep. (BAT)	Crude steel	kt	11,362		5,806	4.89	0.25	3,676	58.23	1,390										2,408	20,802	2,600	5,289							2,408		20,802	2,600

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960									
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653									
										2,884																							2,563		321					
										8,769																									144					
											5,624																						5,127		420					
																																						4,693		
																						172,779																12,649	
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164		172,779		1,534	1,457		923			10,960	11,653	11,362	7,690		822		4,693	12,649	

Table A-88: Energy and material flow table for the UK iron and steel sector: site 8b - HIsarna wks, MDEA sep. (BAT)

8s	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	127	468									13,832	
Basic oxygen furnace	Hot metal	kt	11,653				0.15	269													149	106	389							926		216	
Continuous caster	Liquid steel	kt	11,362					153													4.90	23.49	86.21										
Hot rolling mill	SF steel	kt	7,690					2,882													123	161	592									44.96	
Condensor turbine	Electricity	GWh	1,641					718													6,463										783	1,641
ASU	O2	Mm3	3,768																		73.82	482	1,770										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23												431	391	1,436									48.68	
Losses/flaring																					1,088												
MDEA sep. equipment	CO2	kt	9,810																		6,403	350	1,284										
Hlsarna wks, max scrap, MDEA sep.	Crude steel	kt	11,362		4,503	4.89	0.40	6,896	58.23	1,078											926	14,925	1,641	6,024							926		14,925	1,641

Material inputs																										Material outputs																			
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716							838			3,162									1,190			716			8,500											
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653										
										11,653																						11,362		191						
											8,436																						7,690		631						
																																						3,768		
																						172,779																9,810	
12,495					716	8,012	207	620	3,694	11,653	8,436	838	720		3,779				203	164		172,779		1,190	1,457		716			8,500	11,653	11,362	7,690		822			3,768	9,810	

Table A-89: Energy and material flow table for the UK iron and steel sector: site 8s - HIsarna wks, max scrap, MDEA sep.

8bs	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	166	429									14,658	
Basic oxygen furnace	Hot metal	kt	11,653					619														84.44	219							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														49.29	128										
Continuous caster	Liquid steel	kt	8,550					79.17														18.35	47.49										
Hot rolling mill	SF steel	kt	5,127					265												929	47.45	109	282									68.36	
Condensor turbine	Electricity	GWh	2,019					811												65.54	7,950											964	2,019
ASU	O2	Mm3	3,768																		73.82	628	1,624										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,925	58.23											853	431	509	1,318									48.68	
Losses/flaring																				139	1,189												
MDEA sep. equipment	CO2	kt	9,810																		6,403	455	1,178										
Hlsarna wks, max scrap, MDEA sep. (BAT	Crude steel	kt	11,362		4,503	4.89	0.25	3,857	58.23	1,078										1,987	16,283	2,019	5,225							1,987		16,283	2,019

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716							838			3,162									1,190			716			8,500										
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653										
										2,884																							2,563		321					
										8,769																						8,550		144					
											5,624																						5,127		420					
																																						3,768		
																						172,779																	9,810	
12,495					716	8,012	207	620	3,694	11,653	5,624	838	720		3,768				203	164		172,779		1,190	1,457		716			8,500	11,653	8,550	7,690		885			3,768	9,810	

Table A-90: Energy and material flow table for the UK iron and steel sector: site 8bs - HIsarna wks, max scrap, MDEA sep. (BAT)

8.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	365	402									17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	236	259							1,123		216	
Continuous caster	SF steel	kt	11,362					153													4.90	52.25	57.44										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664													123	359	395									44.96	
Condensor turbine	Electricity	GWh	4,522					1,979													17,807										2,158	4,522
ASU	O2	Mm3	4,693																		73.82	1,073	1,179										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	870	957									48.68	
Losses/flaring																					1,471												
VPSA sep. equipment	CO2	kt	12,649																			1,567	1,722										
Hlsarna wks, VPSA sep.	Crude steel	kt	11,362		5,806	4.89	0.40	7,938	58.23	1,390										1,123	20,302	4,522	4,971							1,123		20,302	4,522

Material inputs																											Material outputs																				
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960											
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653											
										11,653																						11,362		191							
											8,436																						7,690		631						
																																						4,693			
																																							12,649	
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164				1,534	1,457		923			10,960	11,653	11,362	7,690		822		4,693	12,649	

Table A-91: Energy and material flow table for the UK iron and steel sector: site 8.v - HIsarna wks, VPSA sep.

8b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960		5,806					1,390											243	420	347									18,900	
Basic oxygen furnace	Liquid steel	kt	11,653					619														166	137							2,408		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														96.76	80.11										
Continuous caster	SF steel	kt	8,550					79.17														36.02	29.82										
Hot rolling mill	Hot-rolled steel	kt	5,127					265												929	47.45	214	177									68.36	
Condensor turbine	Electricity	GWh	4,963					1,663												457	19,542											2,369	4,963
ASU	O2	Mm3	4,693																		73.82	1,232	1,020										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,925	58.23											853	431	999	827									48.68	
Losses/flaring																				169	1,591												
VPSA sep. equipment	CO2	kt	12,649																			1,799	1,489										
Hlsarna wks, VPSA sep. (BAT)	Crude steel	kt	11,362		5,806	4.89	0.25	4,710	58.23	1,390										2,408	21,929	4,963	4,108							2,408		21,929	4,963

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960									
93.35						10,471	207	620	1,235				720		606				203	164					1,457						11,653									
										2,884																							2,563		321					
										8,769																									144					
											5,624																						5,127		420					
																																						4,693		
																																							12,649	
16,084					923	10,471	207	620	1,235	11,653	5,624	1,081	720		4,683				203	164				1,534	1,457		923			10,960	11,653	8,550	7,690		885		4,693	12,649	

Table A-92: Energy and material flow table for the UK iron and steel sector: site 8b.v - HIsarna wks, VPSA sep. (BAT)

8s.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	241	354									13,832	
Basic oxygen furnace	Hot metal	kt	11,653				0.15	269													149	200	295							926		216	
Continuous caster	Liquid steel	kt	11,362					153													4.90	44.41	65.29										
Hot rolling mill	SF steel	kt	7,690					2,882													123	305	449									44.96	
Condensor turbine	Electricity	GWh	3,474					1,520													13,681										1,658	3,474
ASU	O2	Mm3	3,768																		73.82	912	1,340										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23												431	739	1,087									48.68	
Losses/flaring																					1,148												
VPSA sep. equipment	CO2	kt	9,810																			1,032	1,518										
Hlsarna wks, max scrap, VPSA sep.	Crude steel	kt	11,362		4,503	4.89	0.40	7,698	58.23	1,078											926	15,800	3,474	5,108							926		15,800	3,474

Material inputs																									Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limeston e and dolomite	Lime and calcined dolomite	Electrod es	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxid e	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716							838			3,162									1,190			716			8,500										
93.35						8,012	207	620	3,694				720		616				203	164					1,457						11,653										
										11,653																						11,362		191						
											8,436																						7,690		631						
																																						3,768		
																																							9,810	
12,495					716	8,012	207	620	3,694	11,653	8,436	838	720		3,779				203	164				1,190	1,457		716			8,500	11,653	11,362	7,690		822			3,768	9,810	

Table A-93: Energy and material flow table for the UK iron and steel sector: site 8s.v - HIsarna wks, max scrap, VPSA sep.

8bs.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	8,500		4,503					1,078											188	281	314									14,658	
Basic oxygen furnace	Hot metal	kt	11,653					619														143	160							1,987		544	
Thin slab caster	Hot-rolled steel	kt	2,563					158														83.48	93.39										
Continuous caster	Liquid steel	kt	8,550					79.17														31.07	34.76										
Hot rolling mill	SF steel	kt	5,127					265																								68.36	
Condensor turbine	Electricity	GWh	3,852					1,613																								1,838	3,852
ASU	O2	Mm3	3,768																		929	47.45	184	206									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,925	58.23												65.54	15,168											
Losses/flaring																						73.82	1,063	1,189									
VPSA sep. equipment	CO2	kt	9,810																		853	431	862	964								48.68	
																					139	1,249											
Hlsarna wks, max scrap, VPSA sep. (BAT)	Crude steel	kt	11,362		4,503	4.89	0.25	4,659	58.23	1,078											1,987	17,158	3,852	4,309						1,987		17,158	3,852

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
12,402					716							838			3,162									1,190			716			8,500										
93.35						8,012	207	620	3,694				720		606				203	164					1,457						11,653										
										2,884																							2,563		321					
										8,769																						8,550		144					
											5,624																						5,127		420					
																																						3,768		
																																							9,810	
12,495					716	8,012	207	620	3,694	11,653	5,624	838	720		3,768				203	164				1,190	1,457		716			8,500	11,653	8,550	7,690		885			3,768	9,810	

Table A-94: Energy and material flow table for the UK iron and steel sector: site 8bs.v - HIsarna wks, max scrap, VPSA sep. (BAT)

9	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759											
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953											
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754										44.96	
Boiler	Steam	GWh	666					692													105											666	
NGCC turbine generator	Electricity	GWh	7,716					15,148																									7,716
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MIDREX wks	Crude steel	kt	11,362		35.20	4.89	0.39	49,174	68.64					86.16							759	7,716	603									759	7,716

Material inputs																								Material outputs													
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230					
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653								
										11,653																					11,362			191				
											8,436																					7,690		631				
9,984								620	4,200	11,653	8,436		586	29.59	256				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822				

Table A-95: Energy and material flow table for the UK iron and steel sector: site 9 - MIDREX wks

9g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441										
Boiler	Steam	GWh	571					594													90.38										571	
NGCC turbine generator	Electricity	GWh	7,660					15,038																								7,660
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MIDREX gnf.wks	Crude steel	kt	11,362		140	4.89	0.25	47,656	58.23												620	7,660	603									620	7,660

Material inputs																							Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321					
										8,769																						8,550			219				
											5,624																						5,127		497					
9,984								620	4,200	11,653	5,624		586	29.59	256				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037					

Table A-96: Energy and material flow table for the UK iron and steel sector: site 9g - MIDREX gnf.wks

9b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460										
Boiler	Steam	GWh	556					578													87.99										556	
NGCC turbine generator	Electricity	GWh	5,948					11,677																								5,948
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MIDREX wks (BAT)	Crude steel	kt	11,362		150	4.89	0.25	43,606	58.23												605	5,948	603									605	5,948

Material inputs																										Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			144						
											5,624																					5,127		420						
9,984								620	4,200	11,653	5,624		586	10.49	256				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885					

Table A-97: Energy and material flow table for the UK iron and steel sector: site 9b - MIDREX wks (BAT)

9.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940															759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754									44.96	
Boiler	Steam	GWh	666					692													105											666	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MIDREX wks, imp.elec.	Crude steel	kt	11,362		35.20	4.89	0.39	34,026	68.64					86.16							759		8,319									759	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653										
										11,653																					11,362			191					
											8,436																					7,690		631					
9,984								620	4,200	11,653	8,436		586	29.59	256				247	40.63	7,230					1,923				11,653	11,362	7,690	7,230	822					

Table A-98: Energy and material flow table for the UK iron and steel sector: site 9.i - MIDREX wks, imp.elec.

9g.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940															759									
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953									
Continuous caster	SF steel	kt	11,362					84.16															142									
Hot rolling mill	Hot rolled steel	kt	7,690					3,275															661									
Boiler	Steam	GWh	571					594													90.38										571	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
MIDREX gnf.wks, imp.elec.	Crude steel	kt	11,362		140	4.89	0.25	33,573	58.23												620		8,342								620	

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653										
										11,653																					11,362			291					
											8,436																					7,690		746					
9,984								620	4,200	11,653	8,436		586	29.59	256				247	40.63	7,230					1,923				11,653	11,362	7,690	7,230	1,037					

Table A-99: Energy and material flow table for the UK iron and steel sector: site 9g.i - MIDREX gnf.wks, imp.elec.

9b.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast fumace gas	TGR-BF process gas	Excess syngas	Basic oxygen fumace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen fumace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940															759									
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					79.17															65.83									
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44		460									
Boiler	Steam	GWh	556					578													87.99										556	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
MIDREX wks, imp.elec. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	31,929	58.23												605		6,551								605	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321					
										8,769																						8,550			144				
											5,624																						5,127		420				
9,984								620	4,200	11,653	5,624		586	10.49	256				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885				

Table A-100: Energy and material flow table for the UK iron and steel sector: site 9b.i - MIDREX wks, imp.elec. (BAT)

10	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754									44.96	
Boiler	Steam	GWh	5,574					5,793													882										5,574	
NGCC turbine generator	Electricity	GWh	8,771					17,218																								8,771
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	6,330																		4,132	1,054										
MIDREX wks MDEA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	56,344	68.64					86.16							5,668	8,771	603								5,668	8,771

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																						86,464																6,330	
9,984								620	4,200	11,653	8,436		586	29.59	256				247	40.63	7,230	86,464				1,923					11,653	11,362	7,690	7,230	822				6,330	

Table A-101: Energy and material flow table for the UK iron and steel sector: site 10 - MIDREX wks MDEA sep.

10g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441										
Boiler	Steam	GWh	5,465					5,680													865										5,465	
NGCC turbine generator	Electricity	GWh	8,711					17,101																								8,711
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO_2	kt	6,311																		4,120	1,051										
MIDREX gnf.wks MDEA sep.	Crude steel	kt	11,362		140	4.89	0.25	54,806	58.23												5,514	8,711	603								5,514	8,711

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230					
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653									
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																						86,214																6,311	
9,984								620	4,200	11,653	5,624		586	29.59	256				247	40.63	7,230	86,214				1,923				11,653	8,550	7,690	7,230	1,037				6,311	

Table A-102: Energy and material flow table for the UK iron and steel sector: site 10g - MIDREX gnf.wks MDEA sep.

10b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460										
Boiler	Steam	GWh	5,019					5,215													794										5,019	
NGCC turbine generator	Electricity	GWh	6,907					13,559																								6,907
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	5,755																		3,756	958										
MIDREX wks MDEA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	50,125	58.23												5,067	6,907	603								5,067	6,907

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																						78,612																5,755	
9,984								620	4,200	11,653	5,624		586	10.49	256				247	40.63	7,230	78,612				1,923					11,653	8,550	7,690	7,230	885				5,755	

Table A-103: Energy and material flow table for the UK iron and steel sector: site 10b - MIDREX wks MDEA sep. (BAT)

10.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754									44.96	
Boiler	Steam	GWh	666					692													105										666	
NGCC turbine generator	Electricity	GWh	9,414					18,480																								9,414
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603								48.68	
VPSA sep. equipment	CO2	kt	6,528																			1,697										
MIDREX wks VPSA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	52,506	68.64					86.16							759	9,414	603								759	9,414

Material inputs																							Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																		7,230					
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653								
										11,653																					11,362			191				
											8,436																					7,690		631				
																																						6,528	
9,984								620	4,200	11,653	8,436		586	29.59	256				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			6,528	

Table A-104: Energy and material flow table for the UK iron and steel sector: site 10.v - MIDREX wks VPSA sep.

10g.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441										
Boiler	Steam	GWh	571					594													90.38										571	
NGCC turbine generator	Electricity	GWh	9,353					18,360																								9,353
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	6,509																			1,692										
MIDREX gnf.wks VPSA sep.	Crude steel	kt	11,362		140	4.89	0.25	50,978	58.23												620	9,353	603									620	9,353

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																						6,509	
9,984								620	4,200	11,653	5,624		586	29.59	256				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037				6,509	

Table A-105: Energy and material flow table for the UK iron and steel sector: site 10g.v - MIDREX gnf.wks VPSA sep.

10b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
MIDREX DRI	Hot metal	kt	7,230					25,940														759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460										
Boiler	Steam	GWh	556					578													87.99										556	
NGCC turbine generator	Electricity	GWh	7,492					14,707																								7,492
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	5,935																			1,543										
MIDREX wks VPSA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	46,635	58.23												605	7,492	603									605	7,492

Material inputs																									Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984																																	7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923				11,653										
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																						5,935	
9,984								620	4,200	11,653	5,624		586	10.49	256				247	40.63	7,230					1,923				11,653	8,550	7,690	7,230	885				5,935	

Table A-106: Energy and material flow table for the UK iron and steel sector: site 10b.v - MIDREX wks VPSA sep. (BAT)

11	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754									44.96	
Boiler	Steam	GWh	5,356					5,566													848										5,356	
NGCC turbine generator	Electricity	GWh	9,395					18,443																								9,395
ASU	O2	Mm3	1,410																		22.18	677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	6,014																													
ULCORED wks, NG, MDEA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	51,981	68.64					86.16							5,449	9,395	603								5,449	9,395

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					1,410		
																						82,152																6,014	
9,984								620	4,200	11,653	8,436		586	29.59	1,410				247	40.63	7,230	82,152				1,923					11,653	11,362	7,690	7,230	822			1,410	6,014	

Table A-107: Energy and material flow table for the UK iron and steel sector: site 11 - ULCORED wks, NG, MDEA sep.

11g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441										
Boiler	Steam	GWh	5,246					5,452													830										5,246	
NGCC turbine generator	Electricity	GWh	9,335					18,326																								9,335
ASU	O2	Mm3	1,410																		22.18	677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	5,995																		3,913	998										
ULCORED gnf.wks, NG, MDEA sep.	Crude steel	kt	11,362		140	4.89	0.25	50,442	58.23												5,295	9,335	603								5,295	9,335

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					1,410			
																						154,556																	
9,984								620	4,200	11,653	5,624		586	29.59	1,410				247	40.63	7,230	154,556				1,923					11,653	8,550	7,690	7,230	1,037			1,410	5,995	

Table A-108: Energy and material flow table for the UK iron and steel sector: site 11g - ULCORED gnf.wks, NG, MDEA sep.

11b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460										
Boiler	Steam	GWh	4,773					4,960													755										4,773	
NGCC turbine generator	Electricity	GWh	7,525					14,772																								7,525
ASU	O2	Mm3	1,410																		22.18	677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	5,404																		3,527	900										
ULCORED wks, NG, MDEA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	45,722	58.23												4,821	7,525	603								4,821	7,525

Material inputs																										Material outputs																			
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			144					
											5,624																						5,127		420					
																																						1,410		
																						73,812																	5,404	
9,984								620	4,200	11,653	5,624		586	10.49	1,410				247	40.63	7,230	73,812				1,923					11,653	8,550	7,690	7,230	885			1,410	5,404	

Table A-109: Energy and material flow table for the UK iron and steel sector: site 11b - ULCORED wks, NG, MDEA sep. (BAT)

11.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759											
Electric arc furnace	Liquid steel	kt	11,653			35.20		0.14	638	10.40					86.16						98.17	4,953											
Continuous caster	SF steel	kt	11,362						38.13												1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690						3,595												123	754										44.96	
Boiler	Steam	GWh	692						719												110											692	
NGCC turbine generator	Electricity	GWh	10,009						19,649																								10,009
ASU	O2	Mm3	1,410																		22.18	677											
Downstream and other	Finished steel	kt	4,646				4.89	0.25	3,122	58.23											431	1,224	603										48.68	
VPSA sep. equipment	CO2	kt	6,215																			1,616											
ULCORED wks, NG, VPSA sep.	Crude steel	kt	11,362			35.20	4.89	0.39	48,341	68.64					86.16						786	10,009	603									786	10,009

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																									
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653			7,230						
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					1,410		
																																						6,215	
9,984								620	4,200	11,653	8,436		586	29.59	1,410				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			1,410	6,215	

Table A-110: Energy and material flow table for the UK iron and steel sector: site 11.v - ULCORED wks, NG, VPSA sep.

11g.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441										
Boiler	Steam	GWh	598					621													94.55										598	
NGCC turbine generator	Electricity	GWh	9,948					19,528																								9,948
ASU	O2	Mm3	1,410																		22.18	677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	6,195																			1,611										
ULCORED gnf.wks, NG, VPSA sep.	Crude steel	kt	11,362		140	4.89	0.25	46,813	58.23												646	9,948	603									646	9,948

Material inputs																								Material outputs																			
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			219				
											5,624																						5,127		497				
																																					1,410		
																																						6,195	
9,984								620	4,200	11,653	5,624		586	29.59	1,410				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			1,410	6,195	

Table A-111: Energy and material flow table for the UK iron and steel sector: site 11g.v - ULCORED gnf.wks, NG, VPSA sep.

11b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579														759										
Electric arc furnace	Liquid steel	kt	11,653			150		627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460										
Boiler	Steam	GWh	582					605													92.16										582	
NGCC turbine generator	Electricity	GWh	8,077					15,856																								8,077
ASU	O2	Mm3	1,410																		22.18	677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	5,584																			1,452										
ULCORED wks, NG, VPSA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	42,451	58.23												631	8,077	603									631	8,077

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653											
										2,884																							2,563		321					
										8,769																					8,550			144						
											5,624																					5,127		420						
																																					1,410			
																																							5,584	
9,984								620	4,200	11,653	5,624		586	10.49	1,410				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			1,410	5,584	

Table A-112: Energy and material flow table for the UK iron and steel sector: site 11b.v - ULCORED wks, NG, VPSA sep. (BAT)

11.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759									
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953									
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28									
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754								44.96	
Boiler	Steam	GWh	5,356					5,566													848										5,356	
ASU	O2	Mm3	1,410																		22.18		677									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
MDEA sep. equipment	CO2	kt	2,946																		3,926		1,002									
ULCORED wks, imp.elec., NG, MDEA sep	Crude steel	kt	11,362		35.20	4.89	0.39	33,539	68.64					86.16							5,449		9,998								5,449	

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230				1,923						11,653										
										11,653																						11,362			191					
											8,436																						7,690		631					
																																					1,410			
																						82,152																	2,946	
9,984								620	4,200	11,653	8,436		586	29.59	1,410				247	40.63	7,230	82,152			1,923					11,653	11,362	7,690	7,230	822			1,410	2,946	

Table A-113: Energy and material flow table for the UK iron and steel sector: site 11.i - ULCORED wks, imp.elec., NG, MDEA sep.

11g.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759									
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					63.33															107									
Hot rolling mill	Hot rolled steel	kt	5,127					2,184															441									
Boiler	Steam	GWh	5,246					5,452													830										5,246	
ASU	O2	Mm3	1,410																		22.18		677									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
MDEA sep. equipment	CO2	kt	2,946																		3,913		998									
ULCORED gnf.wks, imp.elec., NG, MDEA	Crude steel	kt	11,362		140	4.89	0.25	32,116	58.23												5,295		9,938								5,295	

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					1,410			
																						154,556																		
9,984								620	4,200	11,653	5,624		586	29.59	1,410				247	40.63	7,230	154,556				1,923					11,653	8,550	7,690	7,230	1,037			1,410	2,946	

Table A-114: Energy and material flow table for the UK iron and steel sector: site 11g.i - ULCORED gnf.wks, imp.elec., NG, MDEA sep.

11b.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759										
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44		460										
Boiler	Steam	GWh	4,773					4,960													755										4,773	
ASU	O2	Mm3	1,410																		22.18		677										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68		
MDEA sep. equipment	CO2	kt	2,946																		3,527		900										
ULCORED wks, imp.elec., NG, MDEA sep	Crude steel	kt	11,362		150	4.89	0.25	30,950	58.23												4,821		8,128								4,821		

Material inputs																									Material outputs																				
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			144					
											5,624																						5,127		420					
																																						1,410		
																						73,812																	2,946	
9,984								620	4,200	11,653	5,624		586	10.49	1,410				247	40.63	7,230	73,812				1,923					11,653	8,550	7,690	7,230	885			1,410	2,946	

Table A-115: Energy and material flow table for the UK iron and steel sector: site 11b.i - ULCORED wks, imp.elec., NG, MDEA sep. (BAT)

11.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759									
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953									
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28									
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754								44.96	
Boiler	Steam	GWh	692					719													110										692	
ASU	O2	Mm3	1,410																		22.18		677									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
VPSA sep. equipment	CO2	kt	2,946																				1,616									
ULCORED wks, imp.elec., NG, VPSA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	28,692	68.64					86.16							786		10,612								786	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					1,410		
																																						2,946	
9,984								620	4,200	11,653	8,436		586	29.59	1,410				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			1,410	2,946	

Table A-116: Energy and material flow table for the UK iron and steel sector: site 11.v.i - ULCORED wks, imp.elec., NG, VPSA sep.

11g.v.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759									
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					63.33															107									
Hot rolling mill	Hot rolled steel	kt	5,127					2,184															441									
Boiler	Steam	GWh	598					621													94.55										598	
ASU	O2	Mm3	1,410																		22.18		677									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
VPSA sep. equipment	CO2	kt	2,946																				1,611									
ULCORED gnf.wks, imp.elec., NG, VPSA s	Crude steel	kt	11,362		140	4.89	0.25	27,285	58.23												646		10,550								646	

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																									219					
											5,624																						5,127		497					
																																						1,410		
																																							2,946	
9,984								620	4,200	11,653	5,624		586	29.59	1,410				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			1,410	2,946	

Table A-117: Energy and material flow table for the UK iron and steel sector: site 11g.v.i - ULCORED gnf.wks, imp.elec., NG, VPSA sep.

11b.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & POX	Hot metal	kt	7,230					20,579															759									
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					79.17															65.83									
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44		460									
Boiler	Steam	GWh	582					605													92.16										582	
ASU	O2	Mm3	1,410																		22.18		677									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
VPSA sep. equipment	CO2	kt	2,946																				1,452									
ULCORED wks, imp.elec., NG, VPSA sep.	Crude steel	kt	11,362		150	4.89	0.25	26,595	58.23												631		8,680								631	

Material inputs																									Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															1,155																			7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			144					
											5,624																						5,127		420					
																																						1,410		
																																							2,946	
9,984								620	4,200	11,653	5,624		586	10.49	1,410				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			1,410	2,946	

Table A-118: Energy and material flow table for the UK iron and steel sector: site 11b.v.i - ULCORED wks, imp.elec., NG, VPSA sep. (BAT)

12	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759						893					
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953											
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754										44.96	
Boiler	Steam	GWh	10,422					9,938											893		1,649											10,422	
NGCC turbine generator	Electricity	GWh	11,093					21,776																									11,093
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	12,517																		8,170	2,085											
ULCORED wks, coal, MDEA sep.	Crude steel	kt	11,362		3,997	4.89	0.39	39,108	68.64					86.16					893		10,516	11,093	603						893			10,516	11,093

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					2,692		
																						170,983																12,517	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230	170,983				1,923					11,653	11,362	7,690	7,230	822			2,692	12,517	

Table A-119: Energy and material flow table for the UK iron and steel sector: site 12 - ULCORED wks, coal, MDEA sep.

12g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759						893					
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953											
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					63.33														107											
Hot rolling mill	Hot rolled steel	kt	5,127					2,184														441											
Boiler	Steam	GWh	10,650					10,175											893		1,685										10,650	
NGCC turbine generator	Electricity	GWh	11,106					21,802																									11,106
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	12,932																		8,441	2,154											
ULCORED gnf.wks, coal, MDEA sep.	Crude steel	kt	11,362		4,102	4.89	0.25	38,061	58.23										893		10,699	11,106	603						893			10,699	11,106

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					2,692			
																						333,429																12,932	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230	333,429				1,923					11,653	8,550	7,690	7,230	1,037			2,692	12,932	

Table A-120: Energy and material flow table for the UK iron and steel sector: site 12g - ULCORED gnf.wks, coal, MDEA sep.

12b	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					79.17														65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424																								
Boiler	Steam	GWh	9,839					9,332											893		1,557										9,839	
NGCC turbine generator	Electricity	GWh	9,223					18,106																								9,223
ASU	O2	Mm3	2,692																		42.34	1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	11,907																		7,772	1,983										
ULCORED wks, coal, MDEA sep. (BAT)	Crude steel	kt	11,362		4,112	4.89	0.25	32,849	58.23										893		9,888	9,223	603						893			9,888	9,223

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			144						
											5,624																					5,127		420						
																																					2,692			
																						162,643																		
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230	162,643				1,923					11,653	8,550	7,690	7,230	885			2,692	11,907	

Table A-121: Energy and material flow table for the UK iron and steel sector: site 12b - ULCORED wks, coal, MDEA sep. (BAT)

12.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759						893				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953											
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					2,703											893		123	754										44.96	
Boiler	Steam	GWh	716					744													113										716	
NGCC turbine generator	Electricity	GWh	12,371					24,286																								12,371
ASU	O2	Mm3	2,692																		42.34	1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	12,935																			3,363										
ULCORED wks, coal, VPSA sep.	Crude steel	kt	11,362		3,997	4.89	0.39	31,531	68.64					86.16					893		810	12,371	603						893			810	12,371

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653										
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					2,692		
																																						12,935	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230					1,923				11,653	11,362	7,690	7,230	822			2,692	12,935	

Table A-122: Energy and material flow table for the UK iron and steel sector: site 12.v - ULCORED wks, coal, VPSA sep.

12g.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953							893				
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					63.33														107											
Hot rolling mill	Hot rolled steel	kt	5,127					1,291											893			441											
Boiler	Steam	GWh	10,650					646													98.34											621	
NGCC turbine generator	Electricity	GWh	11,106					24,165																									12,310
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	12,914																			3,358											
ULCORED gnf.wks, coal, VPSA sep.	Crude steel	kt	11,362		4,102	4.89	0.25	30,003	58.23										893		670	12,310	603						893			670	12,310

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			219						
											5,624																					5,127		497						
																																					2,692			
																																						12,914	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			2,692	12,914	

Table A-123: Energy and material flow table for the UK iron and steel sector: site 12g.v - ULCORED gnf.wks, coal, VPSA sep.

12b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																	759										
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263							893				
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					79.17														65.83											
Hot rolling mill	Hot rolled steel	kt	5,127					532											893		85.44	460											
Boiler	Steam	GWh	606					630													95.95											606	
NGCC turbine generator	Electricity	GWh	10,439					20,493																									10,439
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	12,304																			3,199											
ULCORED wks, coal, VPSA sep. (BAT)	Crude steel	kt	11,362		4,112	4.89	0.25	25,641	58.23										893		655	10,439	603						893			655	10,439

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321				
										8,769																					8,550			144				
											5,624																					5,127		420				
																																					2,692		
																																						12,304	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			2,692	12,304	

Table A-124: Energy and material flow table for the UK iron and steel sector: site 12b.v - ULCORED wks, coal, VPSA sep. (BAT)

12.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754									44.96	
Boiler	Steam	GWh	10,422					9,938											893		1,649											10,422	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	8,895																		8,170		2,085										
ULCORED wks, imp.elec., coal, MDEA sep.	Crude steel	kt	11,362		3,997	4.89	0.39	17,332	68.64					86.16					893		10,516		11,696						893			10,516	

Material inputs																											Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																					2,692			
																						170,983																	8,895	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230	170,983				1,923					11,653	11,362	7,690	7,230	822			2,692	8,895	

Table A-125: Energy and material flow table for the UK iron and steel sector: site 12.i - ULCORED wks, imp.elec., coal, MDEA sep.

12g.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184															441										
Boiler	Steam	GWh	10,650					10,175											893		1,685										10,650		
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68		
MDEA sep. equipment	CO2	kt	8,895																		8,441		2,154										
ULCORED gnf.wks, imp.elec., coal, MDEA	Crude steel	kt	11,362		4,102	4.89	0.25	16,259	58.23										893		10,699		11,709						893			10,699	

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			219					
											5,624																						5,127		497					
																																					2,692			
																						333,429																			
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230	333,429				1,923					11,653	8,550	7,690	7,230	1,037			2,692	8,895	

Table A-126: Energy and material flow table for the UK iron and steel sector: site 12g.i - ULCORED gnf.wks, imp.elec., coal, MDEA sep.

12b.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44		460										
Boiler	Steam	GWh	9,839					9,332											893		1,557											9,839	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	8,895																		7,772		1,983										
ULCORED wks, imp.elec., coal, MDEA sep	Crude steel	kt	11,362		4,112	4.89	0.25	14,743	58.23										893		9,888		9,826						893			9,888	

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																								144						
											5,624																					5,127		420						
																																						2,692		
																						162,643																	8,895	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230	162,643				1,923					11,653	8,550	7,690	7,230	885			2,692	8,895	

Table A-127: Energy and material flow table for the UK iron and steel sector: site 12b.i - ULCORED wks, imp.elec., coal, MDEA sep. (BAT)

12.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					2,703											893		123		754									44.96	
Boiler	Steam	GWh	716					744													113											716	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
VPSA sep. equipment	CO2	kt	8,895																				3,363										
ULCORED wks, imp.elec., coal, VPSA sep	Crude steel	kt	11,362		3,997	4.89	0.39	7,245	68.64					86.16					893		810		12,974						893			810	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					2,692		
																																						8,895	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			2,692	8,895	

Table A-128: Energy and material flow table for the UK iron and steel sector: site 12.v.i - ULCORED wks, imp.elec., coal, VPSA sep.

12g.v.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127					1,291											893				441										
Boiler	Steam	GWh	10,650					646													98.34										621	
ASU	O_2	Mm3	2,692																		42.34		1,292										
Downstream and other			4,646			4.89	0.25	3,122	58.23												431		1,827								48.68		
VPSA sep. equipment	CO_2	kt	8,895																				3,358										
ULCORED gnf.wks, imp.elec., coal, VPSA	Crude steel	kt	11,362		4,102	4.89	0.25	5,838	58.23										893		670		12,912						893			670	

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			219				
											5,624																					5,127		497					
																																					2,692		
																																						8,895	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			2,692	8,895	

Table A-129: Energy and material flow table for the UK iron and steel sector: site 12g.v.i - ULCORED gnf.wks, imp.elec., coal, VPSA sep.

12b.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		3,962																		759						893				
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					532											893		85.44		460										
Boiler	Steam	GWh	606					630													95.95											606	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
VPSA sep. equipment	CO2	kt	8,895																				3,199										
ULCORED wks, imp.elec., coal, VPSA sep	Crude steel	kt	11,362		4,112	4.89	0.25	5,148	58.23										893		655		11,042						893			655	

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			144				
											5,624																					5,127		420					
																																					2,692		
																																						8,895	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			2,692	8,895	

Table A-130: Energy and material flow table for the UK iron and steel sector: site 12b.v.i - ULCORED wks, imp.elec., coal, VPSA sep. (BAT)

13	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953											
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123	754										44.96	
Boiler	Steam	GWh	19,568					2,572											20,305		3,096											19,568	
NGCC turbine generator	Electricity	GWh	14,196					27,867																									14,196
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	24,253																		15,831	4,039											
ULCORED wks, exs coal syng., MDEA sep	Crude steel	kt	11,362		8,530	4.89	0.39	37,832	68.64					86.16					20,305		19,661	14,196	603						20,305			19,661	14,196

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					5,085		
																						331,298																24,253	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230	331,298				1,923					11,653	11,362	7,690	7,230	822			5,085	24,253	

Table A-131: Energy and material flow table for the UK iron and steel sector: site 13 - ULCORED wks, exs coal syng., MDEA sep.

13g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		140														557		98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563																158			177										
Continuous caster	SF steel	kt	8,550																63.33			107										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			441										
Boiler	Steam	GWh	10,650					7,892											15,251		3,132										19,795	
NGCC turbine generator	Electricity	GWh	11,106					27,893																								14,209
ASU	O2	Mm3	5,085																		79.98	2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	24,668																		16,102	4,108										
ULCORED gnf.wks, exs coal syng., MDEA	Crude steel	kt	11,362		8,635	4.89	0.25	36,815	58.23										20,305		19,844	14,209	603						20,305		19,844	14,209

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																				5,085			
																						636,012																
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230	636,012				1,923					11,653	8,550	7,690	7,230	1,037			5,085	24,668	

Table A-132: Energy and material flow table for the UK iron and steel sector: site 13g - ULCORED gnf.wks, exs coal syng., MDEA sep.

13b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263											
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					79.17														65.83											
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460											
Boiler	Steam	GWh	18,985					3,981											18,214		3,004											18,985	
NGCC turbine generator	Electricity	GWh	12,326					24,197																									12,326
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	23,643																		15,432	3,937											
ULCORED wks, exs coal syng., MDEA sep	Crude steel	kt	11,362		8,645	4.89	0.25	31,497	58.23										20,305		19,033	12,326	603						20,305			19,033	12,326

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					5,085		
																						322,958																
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230	322,958				1,923					11,653	8,550	7,690	7,230	885			5,085	23,643	

Table A-133: Energy and material flow table for the UK iron and steel sector: site 13b - ULCORED wks, exs coal syng., MDEA sep. (BAT)

13.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14		10.40					86.16					638		98.17	4,953							20,305				
Continuous caster	SF steel	kt	11,362																38.13		1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690																3,595		123	754										44.96	
Boiler	Steam	GWh	761																889		120											761	
Turbine generator	Electricity	GWh	16,449					27,562											13,053														16,449
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	24,202																			6,293										
ULCORED wks, exs coal syng., VPSA sep	Crude steel	kt	11,362		8,530	4.89	0.39	28,593	68.64					86.16					20,305		854	16,449	603						20,305			854	16,449

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					5,085		
																																					24,202	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			5,085	24,202	

Table A-134: Energy and material flow table for the UK iron and steel sector: site 13.v - ULCORED wks, exs coal syng., VPSA sep.

13g.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		140														557		98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563																158			177										
Continuous caster	SF steel	kt	8,550																63.33			107										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			441										
Boiler	Steam	GWh	10,650																779		105										666	
Turbine generator	Electricity	GWh	11,106					25,817											14,472													16,317
ASU	O2	Mm3	5,085																		79.98	2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	1,224	603								48.68	
VPSA sep. equipment	CO2	kt	23,912																			6,217										
ULCORED gnf.wks, exs coal syng., VPSA	Crude steel	kt	11,362		8,635	4.89	0.25	26,848	58.23										20,305		715	16,317	603						20,305			715	16,317

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					5,085		
																																						23,912	
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			5,085	23,912	

Table A-135: Energy and material flow table for the UK iron and steel sector: site 13g.v - ULCORED gnf.wks, exs coal syng., VPSA sep.

13b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		150														627			3,263											
Thin slab caster	Hot-rolled steel	kt	2,563																158			177											
Continuous caster	SF steel	kt	8,550																79.17			65.83											
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44	460											
Boiler	Steam	GWh	651																761		103											651	
Turbine generator	Electricity	GWh	14,367					20,311											15,164														14,367
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	22,996																			5,979											
ULCORED wks, exs coal syng., VPSA sep	Crude steel	kt	11,362		8,645	4.89	0.25	21,342	58.23										20,305		700	14,367	603						20,305			700	14,367

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																				5,085			
																																						22,996	
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885		5,085	22,996	

Table A-136: Energy and material flow table for the UK iron and steel sector: site 13b.v - ULCORED wks, exs coal syng., VPSA sep. (BAT)

13.i	Main output			Energy inputs																		Energy outputs										
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																		759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754									44.96	
Boiler	Steam	GWh	19,568					2,572											20,305		3,096											19,568	
ASU	O2	Mm3	5,085																		79.98		2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	19,617																		15,831		4,039										
ULCORED wks, imp.elec., exs coal syng.,	Crude steel	kt	11,362		8,530	4.89	0.39	9,965	68.64					86.16					20,305		19,661		14,798						20,305			19,661	

Material inputs																										Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230				1,923					11,653											
										11,653																					11,362			191						
											8,436																					7,690		631						
																																					5,085			
																						331,298																	19,617	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230	331,298				1,923				11,653	11,362	7,690	7,230	822			5,085	19,617	

Table A-137: Energy and material flow table for the UK iron and steel sector: site 13.i - ULCORED wks, imp.elec., exs coal syng., MDEA sep.

13g.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																		759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127					2,184															441										
Boiler	Steam	GWh	10,650					2,837											20,305		3,132											19,795	
ASU	O2	Mm3	5,085																		79.98		2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	19,617																		16,102		4,108										
ULCORED gnf.wks, imp.elec., exs coal syr	Crude steel	kt	11,362		8,635	4.89	0.25	8,922	58.23										20,305		19,844		14,811						20,305			19,844	

Material inputs																								Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653										
										2,884																						2,563		321						
										8,769																					8,550			219						
											5,624																					5,127		497						
																																					5,085			
																						636,012																		
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230	636,012				1,923				11,653	8,550	7,690	7,230	1,037			5,085	19,617	

Table A-138: Energy and material flow table for the UK iron and steel sector: site 13g.i - ULCORED gnf.wks, imp.elec., exs coal syng., MDEA sep.

13b.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																		759					20,305				
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					79.17															65.83									
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44		460									
Boiler	Steam	GWh	18,985					3,981											18,214		3,004											18,985	
ASU	O2	Mm3	5,085																		79.98		2,440									
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431		1,827									48.68	
MDEA sep. equipment	CO2	kt	19,617																		15,432		3,937									
ULCORED wks, imp.elec., exs coal syng.,	Crude steel	kt	11,362		8,645	4.89	0.25	7,300	58.23										20,305		19,033		12,929					20,305			19,033	

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																								144						
											5,624																					5,127		420						
																																					5,085			
																						322,958																19,617	
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230	322,958				1,923					11,653	8,550	7,690	7,230	885			5,085	19,617	

Table A-139: Energy and material flow table for the UK iron and steel sector: site 13b.i - ULCORED wks, imp.elec., exs coal syng., MDEA sep. (BAT)

13.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	235	524						20,305				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14		10.40					86.16					638		98.17	1,535	3,417										
Continuous caster	SF steel	kt	11,362																38.13		1.22	8.46	18.83										
Hot rolling mill	Hot rolled steel	kt	7,690																3,595		123	234	520									44.96	
Boiler	Steam	GWh	761																889		120											761	
Turbine generator	Electricity	GWh	5,286																13,053														5,286
ASU	O2	Mm3	5,085																		79.98	756	1,684										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	566	1,260									48.68	
VPSA sep. equipment	CO2	kt	19,617																			1,951	4,342										
ULCORED wks, imp.elec., exs coal syng.,	Crude steel	kt	11,362		8,530	4.89	0.39	1,030	68.64					86.16					20,305		854	5,286	11,766						20,305			854	5,286

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																						5,085		
																																							19,617	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			5,085	19,617	

Table A-140: Energy and material flow table for the UK iron and steel sector: site 13.v.i - ULCORED wks, imp.elec., exs coal syng., VPSA sep.

13g.v.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	264	496						20,305				
Electric arc furnace	Liquid steel	kt	11,653		140														557		98.17	1,719	3,233										
Thin slab caster	Hot-rolled steel	kt	2,563																158			61.40	115										
Continuous caster	SF steel	kt	8,550																63.33			37.10	69.77										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			153	288										
Boiler	Steam	GWh	10,650																779		105											666	
Turbine generator	Electricity	GWh	5,874																14,503														5,874
ASU	O2	Mm3	5,085																		79.98	847	1,593										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	634	1,193									48.68	
VPSA sep. equipment	CO2	kt	19,617																			2,158	4,059										
ULCORED gnf.wks, imp.elec., exs coal syn	Crude steel	kt	11,362		8,635	4.89	0.25	1,061	58.23										20,305		715	5,874	11,046						20,305			715	5,874

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					5,085		
																																						19,617	
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			5,085	19,617	

Table A-141: Energy and material flow table for the UK iron and steel sector: site 13g.v.i - ULCORED gnf.wks, imp.elec., exs coal syng., VPSA sep.

13b.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & shell gasifier	Hot metal	kt	7,230		8,495																	311	448						20,305				
Electric arc furnace	Liquid steel	kt	11,653		150														627			1,339	1,924										
Thin slab caster	Hot-rolled steel	kt	2,563																158			72.56	104										
Continuous caster	SF steel	kt	8,550																79.17			27.01	38.83										
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44	189	271										
Boiler	Steam	GWh	651																761		103											651	
Turbine generator	Electricity	GWh	6,141																15,164														6,141
ASU	O2	Mm3	5,085																		79.98	1,001	1,439										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23										2,092		431	749	1,077									48.68	
VPSA sep. equipment	CO2	kt	19,617																			2,453	3,526										
ULCORED wks, imp.elec., exs coal syng.,	Crude steel	kt	11,362		8,645	4.89	0.25	1,030	58.23										20,305		700	6,141	8,829						20,305			700	6,141

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					5,085			
																																						19,617		
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			5,085	19,617	

Table A-142: Energy and material flow table for the UK iron and steel sector: site 13b.v.i - ULCORED wks, imp.elec., exs coal syng., VPSA sep. (BAT)

14	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993																					
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953							893				
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					2,703											893		123	754										44.96	
Boiler	Steam	GWh	8,963					9,315													1,418											8,963	
NGCC turbine generator	Electricity	GWh	10,779					21,161																									10,779
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	10,635																		6,942	1,771											
ULCORED wks, bio., MDEA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	36,977	68.64		5,993			86.16					893		9,057	10,779	603						893			9,057	10,779

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																						2,692		
																						145,277																	10,635	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230	145,277				1,923					11,653	11,362	7,690	7,230	822			2,692	10,635	

Table A-143: Energy and material flow table for the UK iron and steel sector: site 14 - ULCORED wks, bio., MDEA sep.

14g	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993											759							893				
Electric arc furnace	Liquid steel	kt	11,653			140			557												98.17	4,953											
Thin slab caster	Hot-rolled steel	kt	2,563						158													177											
Continuous caster	SF steel	kt	8,550						63.33													107											
Hot rolling mill	Hot rolled steel	kt	5,127						2,184													441											
Boiler	Steam	GWh	10,650						8,715										893		1,463											9,245	
NGCC turbine generator	Electricity	GWh	11,106						21,209																								10,804
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	11,120																		7,259	1,852											
ULCORED gnf.wks, bio., MDEA sep.	Crude steel	kt	11,362		140	4.89	0.25	36,008	58.23		5,993								893		9,293	10,804	603						893			9,293	10,804

Material inputs																									Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321				
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					2,692		
																						286,710																11,120	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230	286,710				1,923					11,653	8,550	7,690	7,230	1,037			2,692	11,120	

Table A-144: Energy and material flow table for the UK iron and steel sector: site 14g - ULCORED gnf.wks, bio., MDEA sep.

14b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993											759											
Electric arc furnace	Liquid steel	kt	11,653		150			627														3,263											
Thin slab caster	Hot-rolled steel	kt	2,563					158														177											
Continuous caster	SF steel	kt	8,550					79.17														65.83											
Hot rolling mill	Hot rolled steel	kt	5,127					1,424													85.44	460											
Boiler	Steam	GWh	8,380					7,816											893		1,326											8,380	
NGCC turbine generator	Electricity	GWh	8,910					17,491																									8,910
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	10,025																		6,543	1,670											
ULCORED wks, bio., MDEA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	30,717	58.23		5,993								893		8,429	8,910	603						893			8,429	8,910

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					2,692			
																						136,937																		
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230	136,937				1,923					11,653	8,550	7,690	7,230	885			2,692	10,025	

Table A-145: Energy and material flow table for the UK iron and steel sector: site 14b - ULCORED wks, bio., MDEA sep. (BAT)

14.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993											759							893				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953											
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690					1,810											893		123	754										44.96	
Boiler	Steam	GWh	716					744													113											716	
NGCC turbine generator	Electricity	GWh	11,866					23,293																									11,866
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	10,990																			2,857											
ULCORED wks, bio., VPSA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	29,646	68.64		5,993			86.16					893		810	11,866	603						893			810	11,866

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																						7,690		631					
																																					2,692			
																																						10,990		
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			2,692	10,990	

Table A-146: Energy and material flow table for the UK iron and steel sector: site 14.v - ULCORED wks, bio., VPSA sep.

14g.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993																					
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953						893				
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127					1,291											893			441										
Boiler	Steam	GWh	10,650					646													98.34										621	
NGCC turbine generator	Electricity	GWh	11,106					23,173																								11,804
ASU	O2	Mm3	2,692																		42.34	1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	10,970																			2,852										
ULCORED gnf.wks, bio., VPSA sep.	Crude steel	kt	11,362		140	4.89	0.25	29,010	58.23		5,993								893		670	11,804	603						893			670	11,804

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			219				
											5,624																						5,127		497				
																																					2,692		
																																						10,970	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			2,692	10,970	

Table A-147: Energy and material flow table for the UK iron and steel sector: site 14g.v - ULCORED gnf.wks, bio., VPSA sep.

14b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993											759							893				
Electric arc furnace	Liquid steel	kt	11,653			150			627													3,263											
Thin slab caster	Hot-rolled steel	kt	2,563						158													177											
Continuous caster	SF steel	kt	8,550						79.17													65.83											
Hot rolling mill	Hot rolled steel	kt	5,127						532										893		85.44	460											
Boiler	Steam	GWh	606						630												95.95											606	
NGCC turbine generator	Electricity	GWh	9,934						19,501																								9,934
ASU	O2	Mm3	2,692																		42.34	1,292											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	10,359																			2,693											
ULCORED wks, bio., VPSA sep. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	24,649	58.23		5,993								893		655	9,934	603						893			655	9,934

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					2,692			
																																						10,359	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			2,692	10,359	

Table A-148: Energy and material flow table for the UK iron and steel sector: site 14b.v - ULCORED wks, bio., VPSA sep. (BAT)

14.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953						893				
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754									44.96	
Boiler	Steam	GWh	8,963					8,422											893		1,418											8,963	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	7,115																		6,942		1,771										
ULCORED wks, imp.elec., bio., MDEA sep	Crude steel	kt	11,362		35.20	4.89	0.39	15,815	68.64		5,993			86.16					893		9,057		11,382						893			9,057	

Material inputs																											Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																					2,692			
																						145,277																	7,115	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230	145,277				1,923				11,653	11,362	7,690	7,230	822			2,692	7,115	

Table A-149: Energy and material flow table for the UK iron and steel sector: site 14.i - ULCORED wks, imp.elec., bio., MDEA sep.

14g.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759										
Electric arc furnace	Liquid steel	kt	11,653			140															98.17		4,953						893				
Thin slab caster	Hot-rolled steel	kt	2,563																				177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127																				441										
Boiler	Steam	GWh	10,650					8,715											893		1,463											9,245	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646				4.89	0.25	3,122	58.23											431		1,827									48.68	
MDEA sep. equipment	CO2	kt	7,115																		7,259		1,852										
ULCORED gnf.wks, imp.elec., bio., MDEA	Crude steel	kt	11,362			140	4.89	0.25	14,799	58.23		5,993							893		9,293		11,407						893			9,293	

Material inputs																								Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					2,692		
																						286,710																	7,115	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230	286,710				1,923					11,653	8,550	7,690	7,230	1,037			2,692	7,115	

Table A-150: Energy and material flow table for the UK iron and steel sector: site 14g.i - ULCORED gnf.wks, imp.elec., bio., MDEA sep.

14b.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759						893				
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,424															460										
Boiler	Steam	GWh	8,380					7,816											893		1,326											8,380	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
MDEA sep. equipment	CO2	kt	7,115																		6,543		1,670										
ULCORED wks, imp.elec., bio., MDEA sep	Crude steel	kt	11,362		150	4.89	0.25	13,226	58.23		5,993								893		8,429		9,513						893			8,429	

Material inputs																									Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			144					
											5,624																						5,127		420					
																																						2,692		
																						136,937																	7,115	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230	136,937				1,923					11,653	8,550	7,690	7,230	885			2,692	7,115	

Table A-151: Energy and material flow table for the UK iron and steel sector: site 14b.i - ULCORED wks, imp.elec., bio., MDEA sep. (BAT)

14.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759						893				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690					2,703											893		123		754									44.96	
Boiler	Steam	GWh	716					744													113											716	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
VPSA sep. equipment	CO2	kt	7,115																				2,857										
ULCORED wks, imp.elec., bio., VPSA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	7,245	68.64		5,993			86.16					893		810		12,468						893			810	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					2,692		
																																						7,115	
9,984								620	4,200	11,653	8,436		586	29.59	2,692				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			2,692	7,115	

Table A-152: Energy and material flow table for the UK iron and steel sector: site 14.v.i - ULCORED wks, imp.elec., bio., VPSA sep.

14g.v.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759						893				
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127					1,291											893				441										
Boiler	Steam	GWh	10,650					646													98.34											621	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
VPSA sep. equipment	CO2	kt	7,115																				2,852										
ULCORED gnf.wks, imp.elec., bio., VPSA	Crude steel	kt	11,362		140	4.89	0.25	5,838	58.23		5,993								893		670		12,407						893			670	

Material inputs																									Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										2,884																							2,563		321					
										8,769																						8,550			219					
											5,624																						5,127		497					
																																							2,692		
																																							7,115	
9,984								620	4,200	11,653	5,624		586	29.59	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	1,037			2,692	7,115	

Table A-153: Energy and material flow table for the UK iron and steel sector: site 14g.v.i - ULCORED gnf.wks, imp.elec., bio., VPSA sep.

14b.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								5,993												759										
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263						893				
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					532											893		85.44		460										
Boiler	Steam	GWh	606					630													95.95											606	
ASU	O2	Mm3	2,692																		42.34		1,292										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
VPSA sep. equipment	CO2	kt	7,115																				2,693										
ULCORED wks, imp.elec., bio., VPSA sep.	Crude steel	kt	11,362		150	4.89	0.25	5,148	58.23		5,993								893		655		10,536						893			655	

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															2,436																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321				
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					2,692		
																																						7,115	
9,984								620	4,200	11,653	5,624		586	10.49	2,692				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			2,692	7,115	

Table A-154: Energy and material flow table for the UK iron and steel sector: site 14b.v.i - ULCORED wks, imp.elec., bio., VPSA sep. (BAT)

15	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850																						
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17	4,953							20,305				
Continuous caster	SF steel	kt	11,362					38.13													1.22	27.28											
Hot rolling mill	Hot rolled steel	kt	7,690																3,595		123	754										44.96	
Boiler	Steam	GWh	16,439					2,509											16,710		2,601											16,439	
NGCC turbine generator	Electricity	GWh	13,524					26,548																									13,524
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	1,224	603									48.68	
MDEA sep. equipment	CO2	kt	20,218																		13,197	3,367											
ULCORED wks, exs bio.syng., MDEA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	30,795	68.64		12,850			86.16					20,305		16,533	13,524	603						20,305			16,533	13,524

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					5,085		
																						276,180																20,218	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230	276,180				1,923					11,653	11,362	7,690	7,230	822		5,085	20,218	

Table A-155: Energy and material flow table for the UK iron and steel sector: site 15 - ULCORED wks, exs bio.syng., MDEA sep.

15g	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850											759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563					158														177										
Continuous caster	SF steel	kt	8,550					63.33														107										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			441										
Boiler	Steam	GWh	10,650					3,487											16,061		2,646										16,720	
NGCC turbine generator	Electricity	GWh	11,106					26,596																								13,548
ASU	O2	Mm3	5,085																		79.98	2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	20,703																		13,514	3,448										
ULCORED gnf.wks, exs bio.syng., MDEA s	Crude steel	kt	11,362		140	4.89	0.25	31,924	58.23		12,850								20,305		16,769	13,548	603					20,305			16,769	13,548

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653									
										2,884																							2,563		321				
										8,769																					8,550			219				
											5,624																					5,127		497				
																																				5,085			
																						533,781															20,703	
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230	533,781				1,923					11,653	8,550	7,690	7,230	1,037			5,085	20,703	

Table A-156: Energy and material flow table for the UK iron and steel sector: site 15g - ULCORED gnf.wks, exs bio.syng., MDEA sep.

15b	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850											759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		150														627			3,263										
Thin slab caster	Hot-rolled steel	kt	2,563																158			177										
Continuous caster	SF steel	kt	8,550																79.17			65.83										
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44	460										
Boiler	Steam	GWh	15,856					2,581											15,956		2,509										15,856	
NGCC turbine generator	Electricity	GWh	11,654					22,878																								11,654
ASU	O2	Mm3	5,085																		79.98	2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	1,224	603								48.68	
MDEA sep. equipment	CO2	kt	19,608																		12,799	3,266										
ULCORED wks, exs bio.syng., MDEA sep.	Crude steel	kt	11,362		150	4.89	0.25	26,520	58.23		12,850								20,305		15,904	11,654	603						20,305		15,904	11,654

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	10.49	256				247	40.63	7,230				1,923						11,653									
										2,884																							2,563		321				
										8,769																					8,550			144				
											5,624																					5,127		420				
																																				5,085			
																						267,840																
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230	267,840			1,923					11,653	8,550	7,690	7,230	885			5,085	19,608	

Table A-157: Energy and material flow table for the UK iron and steel sector: site 15b - ULCORED wks, exs bio.syng., MDEA sep. (BAT)

15.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850																					
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14		10.40					86.16								759							20,305				
Continuous caster	SF steel	kt	11,362																638		98.17	4,953											
Hot rolling mill	Hot rolled steel	kt	7,690																38.13		1.22	27.28											
Boiler	Steam	GWh	761																3,595		123	754										44.96	
Turbine generator	Electricity	GWh	15,338					24,820											889		120											761	
ASU	O2	Mm3	5,085																13,053														15,338
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,030	58.23												79.98	2,440											
VPSA sep. equipment	CO2	kt	19,931																2,092		431	1,224	603									48.68	
ULCORED wks, exs bio.syng., VPSA sep.	Crude steel	kt	11,362		35.20	4.89	0.39	25,850	68.64		12,850			86.16					20,305		854	15,338	603						20,305			854	15,338

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																					5,085			
																																							19,931	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			5,085	19,931	

Table A-158: Energy and material flow table for the UK iron and steel sector: site 15.v - ULCORED wks, exs bio.syng., VPSA sep.

15g.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850											759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		140														557		98.17	4,953										
Thin slab caster	Hot-rolled steel	kt	2,563																158			177										
Continuous caster	SF steel	kt	8,550																63.33			107										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			441										
Boiler	Steam	GWh	10,650																779		105										666	
Turbine generator	Electricity	GWh	11,106					20,733											16,564													15,105
ASU	O2	Mm3	5,085																		79.98	2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	1,224	603								48.68	
VPSA sep. equipment	CO2	kt	19,251																			5,005										
ULCORED gnf.wks, exs bio.syng., VPSA s	Crude steel	kt	11,362		140	4.89	0.25	21,795	58.23		12,850								20,305		715	15,105	603						20,305			715	15,105

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230				1,923						11,653									
										2,884																							2,563		321				
										8,769																						8,550			219				
											5,624																						5,127		497				
																																				5,085			
																																					19,251		
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230				1,923						11,653	8,550	7,690	7,230	1,037			5,085	19,251	

Table A-159: Energy and material flow table for the UK iron and steel sector: site 15g.v - ULCORED gnf.wks, exs bio.syng., VPSA sep.

15b.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850											759							20,305				
Electric arc furnace	Liquid steel	kt	11,653		150																	3,263											
Thin slab caster	Hot-rolled steel	kt	2,563																			177											
Continuous caster	SF steel	kt	8,550																			65.83											
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44	460											
Boiler	Steam	GWh	651																761		103											651	
Turbine generator	Electricity	GWh	13,213					16,566											16,060														13,213
ASU	O2	Mm3	5,085																		79.98	2,440											
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	1,224	603									48.68	
VPSA sep. equipment	CO2	kt	18,558																			4,825											
ULCORED wks, exs bio.syng., VPSA sep.	Crude steel	kt	11,362		150	4.89	0.25	17,628	58.23		12,850								20,305		700	13,213	603						20,305			700	13,213

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																				5,085			
																																						18,558	
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885		5,085	18,558	

Table A-160: Energy and material flow table for the UK iron and steel sector: site 15b.v - ULCORED wks, exs bio.syng., VPSA sep. (BAT)

15.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850												759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					38.13													1.22		27.28										
Hot rolling mill	Hot rolled steel	kt	7,690																3,595		123		754									44.96	
Boiler	Steam	GWh	16,439					4,569											14,650		2,601											16,439	
ASU	O2	Mm3	5,085																		79.98		2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431		1,827									48.68	
MDEA sep. equipment	CO2	kt	15,802																		13,197		3,367										
ULCORED wks, imp.elec., exs bio.syng., M	Crude steel	kt	11,362		35.20	4.89	0.39	6,307	68.64		12,850			86.16					20,305		16,533		14,126						20,305			16,533	

Material inputs																										Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																			7,230						
								620	4,200				586	29.59	256				247	40.63	7,230				1,923					11,653										
										11,653																					11,362			191					
											8,436																					7,690		631					
																																				5,085			
																						276,180																	15,802	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230	276,180			1,923					11,653	11,362	7,690	7,230	822			5,085	15,802	

Table A-161: Energy and material flow table for the UK iron and steel sector: site 15.i - ULCORED wks, imp.elec., exs bio.syng., MDEA sep.

15g.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850												759										
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953						20,305				
Thin slab caster	Hot-rolled steel	kt	2,563					158															177										
Continuous caster	SF steel	kt	8,550					63.33															107										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184				441										
Boiler	Steam	GWh	10,650					3,487											16,061		2,646											16,720	
ASU	O2	Mm3	5,085																		79.98		2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431		1,827									48.68	
MDEA sep. equipment	CO2	kt	15,802																		13,514		3,448										
ULCORED gnf.wks, imp.elec., exs bio.syn	Crude steel	kt	11,362		140	4.89	0.25	5,327	58.23		12,850								20,305		16,769		14,151						20,305			16,769	

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923				11,653											
										2,884																							2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																					5,085			
																						533,781																		
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230	533,781				1,923				11,653	8,550	7,690	7,230	1,037			5,085	15,802	

Table A-162: Energy and material flow table for the UK iron and steel sector: site 15g.i - ULCORED gnf.wks, imp.elec., exs bio.syng., MDEA sep.

15b.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850												759						20,305				
Electric arc furnace	Liquid steel	kt	11,653		150														627				3,263										
Thin slab caster	Hot-rolled steel	kt	2,563																158				177										
Continuous caster	SF steel	kt	8,550																79.17				65.83										
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44		460										
Boiler	Steam	GWh	15,856					2,581											15,956		2,509											15,856	
ASU	O2	Mm3	5,085																		79.98		2,440										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431		1,827									48.68	
MDEA sep. equipment	CO2	kt	15,802																		12,799		3,266										
ULCORED wks, imp.elec., exs bio.syng., M	Crude steel	kt	11,362		150	4.89	0.25	3,642	58.23		12,850								20,305		15,904		12,257						20,305			15,904	

Material inputs																									Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321						
										8,769																					8,550			144						
											5,624																					5,127		420						
																																						5,085			
																						267,840																		15,802	
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230	267,840				1,923					11,653	8,550	7,690	7,230	885			5,085	15,802	

Table A-163: Energy and material flow table for the UK iron and steel sector: site 15b.i - ULCORED wks, imp.elec., exs bio.syng., MDEA sep. (BAT)

15.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850																					
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14		10.40					86.16					638		98.17	1,646	3,306						20,305				
Continuous caster	SF steel	kt	11,362																38.13		1.22	9.07	18.22										
Hot rolling mill	Hot rolled steel	kt	7,690																3,595		123	251	503									44.96	
Boiler	Steam	GWh	761																889		120											761	
Turbine generator	Electricity	GWh	5,299																13,084														5,299
ASU	O2	Mm3	5,085																		79.98	811	1,629										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	607	1,219									48.68	
VPSA sep. equipment	CO2	kt	15,802																			1,723	3,459										
ULCORED wks, imp.elec., exs bio.syng., \	Crude steel	kt	11,362		35.20	4.89	0.39	1,061	68.64		12,850			86.16					20,305		854	5,299	10,642						20,305			854	5,299

Material inputs																								Material outputs																
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230							
								620	4,200				586	29.59	256				247	40.63	7,230					1,923					11,653										
										11,653																					11,362			191						
											8,436																					7,690		631						
																																						5,085		
																																							15,802	
9,984								620	4,200	11,653	8,436		586	29.59	5,085				247	40.63	7,230					1,923					11,653	11,362	7,690	7,230	822			5,085	15,802	

Table A-164: Energy and material flow table for the UK iron and steel sector: site 15.v.i - ULCORED wks, imp.elec., exs bio.syng., VPSA sep.

15g.v.i	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850																					
Electric arc furnace	Liquid steel	kt	11,653		140														557		98.17	1,852	3,101						20,305				
Thin slab caster	Hot-rolled steel	kt	2,563																158			66.14	111										
Continuous caster	SF steel	kt	8,550																63.33			39.96	66.91										
Hot rolling mill	Hot rolled steel	kt	5,127																2,184			165	276										
Boiler	Steam	GWh	10,650																779		105											666	
Turbine generator	Electricity	GWh	5,874																14,503														5,874
ASU	O2	Mm3	5,085																		79.98	912	1,528										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	1,061	58.23										2,060		431	683	1,144									48.68	
VPSA sep. equipment	CO2	kt	15,802																			1,872	3,134										
ULCORED gnf.wks, imp.elec., exs bio.syn	Crude steel	kt	11,362		140	4.89	0.25	1,061	58.23		12,850								20,305		715	5,874	9,834						20,305			715	5,874

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																		7,230						
								620	4,200				586	29.59	256				247	40.63	7,230				1,923						11,653									
										2,884																						2,563		321					
										8,769																					8,550			219					
											5,624																					5,127		497					
																																				5,085			
																																					15,802		
9,984								620	4,200	11,653	5,624		586	29.59	5,085				247	40.63	7,230				1,923						11,653	8,550	7,690	7,230	1,037			5,085	15,802	

Table A-165: Energy and material flow table for the UK iron and steel sector: site 15g.v.i - ULCORED gnf.wks, imp.elec., exs bio.syng., VPSA sep.

15b.v.i	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCORED DRI & FB gasifier	Hot metal	kt	7,230								12,850											357	402						20,305				
Electric arc furnace	Liquid steel	kt	11,653		150																	1,536	1,727										
Thin slab caster	Hot-rolled steel	kt	2,563																			83.26	93.61										
Continuous caster	SF steel	kt	8,550																			30.99	34.84										
Hot rolling mill	Hot rolled steel	kt	5,127																1,424		85.44	217	243										
Boiler	Steam	GWh	651																761		103											651	
Turbine generator	Electricity	GWh	6,504																16,060														6,504
ASU	O2	Mm3	5,085																		79.98	1,149	1,291										
Downstream and other			4,646			4.89	0.25	1,061	58.23										2,060		431	860	967									48.68	
VPSA sep. equipment	CO2	kt	15,802																			2,271	2,554										
ULCORED wks, imp.elec., exs bio.syng., \	Crude steel	kt	11,362		150	4.89	0.25	1,061	58.23		12,850								20,305		700	6,504	7,312						20,305			700	6,504

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
9,984															4,829																			7,230						
								620	4,200				586	10.49	256				247	40.63	7,230					1,923					11,653										
										2,884																						2,563		321					
										8,769																					8,550			144					
											5,624																					5,127		420					
																																					5,085			
																																						15,802	
9,984								620	4,200	11,653	5,624		586	10.49	5,085				247	40.63	7,230					1,923					11,653	8,550	7,690	7,230	885			5,085	15,802	

Table A-166: Energy and material flow table for the UK iron and steel sector: site 15b.v.i - ULCORED wks, imp.elec., exs bio.syng., VPSA sep. (BAT)

16	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCOWIN unit	Hot metal	kt	10,121																				32,996										
Electric arc furnace	Liquid steel	kt	11,653		35.20		0.14	638	10.40					86.16							98.17		4,953										
Continuous caster	SF steel	kt	11,362					153													4.90		110										
Hot rolling mill	Hot rolled steel	kt	7,690					3,595													123		754									44.96	
Boiler	Steam	GWh	571					696													106										670	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
ULCOWIN wks, imp.elec.	Crude steel	kt	11,362		35.20	4.89	0.39	8,205	68.64					86.16							764		40,638									764	

Material inputs																								Material outputs													
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
14,990																							1,134							10,121										
						10,121		620	1,308				586	29.59	135				247	40.63						1,923					11,653										
										11,653																					11,362			191						
											8,436																						7,690		631					
14,990						10,121		620	1,308	11,653	8,436		586	29.59	135				247	40.63			1,134			1,923				10,121	11,653	11,362	7,690		822					

Table A-167: Energy and material flow table for the UK iron and steel sector: site 16 - ULCOWIN wks

16g	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast fumace gas	TGR-BF process gas	Excess syngas	Basic oxygen fumace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen fumace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCOWIN unit	Hot metal	kt	10,121																				32,996									
Electric arc furnace	Liquid steel	kt	11,653		140			557													98.17		4,953									
Thin slab caster	Hot-rolled steel	kt	2,563					158															177									
Continuous caster	SF steel	kt	8,550					63.33															107									
Hot rolling mill	Hot rolled steel	kt	5,127					2,184															441									
Boiler	Steam	GWh	571					594													90.38										571	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827								48.68	
ULCOWIN gnf.wks, imp.elec.	Crude steel	kt	11,362		140	4.89	0.25	6,678	58.23												620		40,500								620	

Material inputs																								Material outputs													
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
14,990																							1,134							10,121									
						10,121		620	1,308				586	29.59	135				247	40.63						1,923					11,653									
										2,884																						2,563		321					
										8,769																					8,550		219					
											5,624																					5,127		497					
14,990						10,121		620	1,308	11,653	5,624		586	29.59	135				247	40.63			1,134			1,923				10,121	11,653	8,550	7,690		1,037				

Table A-168: Energy and material flow table for the UK iron and steel sector: site 16g - ULCOWIN gnf.wks

16b	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
ULCOWIN unit	Hot metal	kt	10,121																				32,996										
Electric arc furnace	Liquid steel	kt	11,653		150			627															3,263										
Thin slab caster	Hot-rolled steel	kt	2,563					158																									
Continuous caster	SF steel	kt	8,550					79.17															65.83										
Hot rolling mill	Hot rolled steel	kt	5,127					1,297													47.45		391									68.36	
Boiler	Steam	GWh	571					447													68.00										430	
Downstream and other	Finished steel	kt	4,646			4.89	0.25	3,122	58.23												431		1,827									48.68	
ULCOWIN wks, imp.elec. (BAT)	Crude steel	kt	11,362		150	4.89	0.25	5,731	58.23												547		38,542									547	

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing materials	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
14,990																							1,134							10,121									
						10,121		620	1,308				586	10.49	135				247	40.63						1,923					11,653									
										2,884																						2,563		321					
										8,769																							144					
											5,624																					5,127		420					
14,990						10,121		620	1,308	11,653	5,624		586	10.49	135				247	40.63			1,134			1,923				10,121	11,653	8,550	7,690		885				

Table A-169: Energy and material flow table for the UK iron and steel sector: site 16b - ULCOWIN wks (BAT)

5.2/6.2	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,327	3,218												2,003		401			454	13.33	34.28	2,418	13.75	4,705					998		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	106	272										
TGRBF	Hot metal	kt	10,960	2,171				2,474						2,106		170		23,056				107	275					28,185					
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	139	356							1,123		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	30.71	78.99										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,776								245		587		899	123	211	543										
Boiler	Steam	GWh	14,732					11,322								1,171		3,782			2,331											14,732	
Condensor turbine	Electricity	GWh	1,362																		5,021											609	1,362
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
ASU - low purity	O2	Mm3	411																		6.46	55.21	142										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	511	1,315									48.68	
Losses/flaring																445		359			1,273												
MDEA sep. equipment	CO2	kt	8,548																		5,580	399	1,025										
TGR-BF wks, MDEA sep.	Crude steel	kt	11,362	5,389		4.89	0.40	18,433	58.23					2,106	656	4,705		28,185		1,123	17,396	1,571	4,042	2,418	13.75	4,705		28,185		1,123	998	17,396	1,571

Material inputs																								Material outputs																		
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851											
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653									
										11,653																					11,362			191					
											8,436																					7,690		631					
																																					411		
																						129,745																	8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166		129,745		2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822			411	8,548	

Table A-170: Energy and material flow table for the UK iron and steel sector: site 5.2/6.2 - TGR-BF [V4] wks, MDEA sep.

5.2/6.2.v	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	2,327	3,218												2,003		401			454	11.67	35.94	2,418	13.75	4,705					998		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	92.51	285										
TGRBF	Hot metal	kt	10,960	2,171				2,474						2,106		170		23,056				93.74	289						28,185				
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	121	374								1,123		216	
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	26.88	82.81										
Hot rolling mill	Hot-rolled steel	kt	7,690					1,776								245		587		899	123	185	569										
Boiler	Steam	GWh	7,486					3,110								1,171		3,782			1,185											7,486	
Condensor turbine	Electricity	GWh	1,362																		5,021											609	1,362
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011											1,790	209
ASU - low purity	O2	Mm3	411																		6.46	48.33	149										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,645	58.23							229				224	431	448	1,379									48.68	
Losses/flaring																445		359			753												
VPSA sep. equipment	CO2	kt	8,548																			545	1,678										
TGR-BF wks, VPSA sep.	Crude steel	kt	11,362	5,389		4.89	0.40	10,221	58.23					2,106	656	4,705		28,185		1,123	10,149	1,571	4,841	2,418	13.75	4,705		28,185		1,123	998	10,149	1,571

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
11,300		3.27	4,071	925	151							1,949								984								4,071	13,851										
1,944	3,269		12,400	145				2.71				57.27			411					18.76				2,994			116	1,070		10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457					11,653										
										11,653																						11,362		191					
											8,436																						7,690		631				
																																					411		
																																						8,548	
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		1,027				203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822			411	8,548	

Table A-171: Energy and material flow table for the UK iron and steel sector: site 5.2/6.2v - TGR-BF [V4] wks, VPSA sep.

7.2	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Hlsarna SR furnace	Hot metal	kt	10,960							1,390		6,097									243	767										17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	495								1,123		216	
Continuous caster	SF steel	kt	11,362					153													4.90	110											
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664													123	754										44.96	
Condensor turbine	Electricity	GWh	3,653					1,599													14,387											1,744	3,653
ASU	O2	Mm3	4,693																		3,107												
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23												431	1,528	299									48.68	
Losses/flaring																					1,442												
Hlsarna wks	Crude steel	kt	11,362			4.89	0.40	7,558	58.23	1,390		6,097								1,123	19,888	3,653	299							1,123		19,888	3,653

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960										
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653										
										11,653																						11,362		191					
											8,436																						7,690		631					
																																					4,693		
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164				1,534	1,457		923			10,960	11,653	11,362	7,690		822			4,693		

Table A-172: Energy and material flow table for the UK iron and steel sector: site 7.2 - Hisarna [bio] wks

8.2	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
HIsarna SR furnace	Hot metal	kt	10,960							1,390		6,097									243	185	582									17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	119	376							1,123		216	
Continuous caster	SF steel	kt	11,362					153													4.90	26.43	83.27										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664												899	123	182	572									44.96	
Condensor turbine	Electricity	GWh	2,030					888													7,993											969	2,030
ASU	O2	Mm3	4,693																		73.82	543	1,709										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	440	1,387									48.68	
Losses/flaring																					1,390												
MDEA sep. equipment	CO2	kt	13,335																		8,704	535	1,686										
HIsarna wks, MDEA sep.	Crude steel	kt	11,362			4.89	0.40	6,847	58.23	1,390		6,097								1,123	19,113	2,030	6,395							1,123		19,113	2,030

Material inputs																										Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960										
93.35						10,471	207	620	1,235				720		616				203	164											11,653									
										11,653															1,457							11,362		191					
											8,436																						7,690		631					
																																					4,693			
																						182,160																13,335	
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164		182,160		1,534	1,457		923			10,960	11,653	11,362	7,690		822			4,693	13,335	

Table A-173: Energy and material flow table for the UK iron and steel sector: site 8.2 - HIsarna [bio] wks, MDEA sep.

8.2.v	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
HIsarna SR furnace	Hot metal	kt	10,960							1,390		6,097									243	359	408									17,834	
Basic oxygen furnace	Liquid steel	kt	11,653				0.15	269													149	231	263							1,123		216	
Continuous caster	SF steel	kt	11,362					153													4.90	51.29	58.41										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,664												899	123	352	401									44.96	
Condensor turbine	Electricity	GWh	4,522					1,979													17,807											2,158	4,522
ASU	O2	Mm3	4,693																		73.82	1,053	1,199										
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,873	58.23											224	431	854	973									48.68	
Losses/flaring																					1,471												
VPSA sep. equipment	CO2	kt	13,335																			1,621	1,846										
HIsarna wks, VPSA sep.	Crude steel	kt	11,362			4.89	0.40	7,938	58.23	1,390		6,097								1,123	20,302	4,522	5,149							1,123		20,302	4,522

Material inputs																								Material outputs														
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
15,990					923							1,081			4,077									1,534			923			10,960									
93.35						10,471	207	620	1,235				720		616				203	164					1,457						11,653									
										11,653																						11,362		191					
											8,436																						7,690		631				
																																					4,693		
																																						13,335	
16,084					923	10,471	207	620	1,235	11,653	8,436	1,081	720		4,693				203	164				1,534	1,457		923			10,960	11,653	11,362	7,690		822		4,693	13,335	

Table A-174: Energy and material flow table for the UK iron and steel sector: site 8.2v - HIsarna [bio] wks, VPSA sep.

1 [2007], 2	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or PCI coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
				kt	kt	kt	kt	GWh	GWh	GWh	kt	kt	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	kt	kt	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Coke oven	Dry coke	kt	4,077	5,638												3,509	703				796	32.08	51.34	4,237	24.09	8,244					1,749		
Sinter plant	Sinter	kt	13,851					79.57							656	156					9.87	145	232										
Blast furnace	Hot metal	kt	10,960	1,242		201		719						3,910	490	942	4,379				2,849	184	295				16,018					243	102
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									269					149	190	305							514			
Continuous caster	SF steel	kt	11,362					136								17.44					4.90	42.17	67.52										
Hot rolling mill	Hot-rolled steel	kt	7,690					2,884								236	138			290	123	290	464									44.96	
Boiler	Steam	GWh	11,517			25.18		577								2,326	9,102				1,822											11,512	
Condensor turbine	Electricity	GWh	1,884																		5,021										609	1,275
Back-pressure turbine	Steam and electricity	GWh	1,999																		2,011										1,790	209
Downstream and other	Finished steel	kt	4,646			4.89	0.25	2,005	58.23							229	576			224	431	702	1,124									48.68	
Losses/flaring																445	1,121				1,029											
Int.wks (Base)	Crude steel	kt	11,362	6,881		231	0.40	6,401	58.23					3,910	1,146	8,129	16,018			514	14,247	1,586	2,539	4,237	24.09	8,244	16,018			514	1,749	14,247	1,586
Electric arc furnace	Liquid steel	kt	3,100		9.37		0.04	170	2.77					22.92							26.12		1,318										
Continuous caster	SF steel	kt	2,827					38.13													1.22		27.28										
Ingot caster	SF steel	kt	171					47.50													2.85		15.34										
Hot rolling mill	Hot-rolled steel	kt	2,733					1,278													43.85		268								15.98		
Boiler	Steam	GWh	185			6.18		141													30.08										190		
Downstream and other	Finished steel	kt				1.30	0.07	534													115		487								12.97		
EAF wks (Base)	Crude steel	kt	3,028		9.37	7.48	0.10	2,209	2.77					22.92							219		2,115								219		
Sector (Base)	Crude steel	kt	14,390	6,881	9.37	239	0.50	8,609	61.00					3,933	1,146	8,129	16,018			514	14,466	1,586	4,654	4,237	24.09	8,244	16,018			514	1,749	14,466	1,586

Material inputs																								Material outputs															
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limeston e and dolomite	Lime and calcined dolomite	Electrod es	O2	N2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxid e	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O2	CO2 (captured)	Flue gas
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	Mm3	kt	Mm3	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	Mm3	kt	kt
																	6,864	3,802																	277	6,864				5,575
11,300		3.27	4,071	925	151							1,949					3,117	10,389		984								4,071	13,851						90.22	3,117				14,536
1,944	3,269		12,400	145				2.71				57.27					8,998	18,263		18.76				2,994			116	1,070		10,960						1,556	8,998				12,647
93.35						10,471	207	620	1,235				720			616	9,323		203	164					1,457						11,653					58.27	9,323				901
										11,653								163													11,362			191	99.98				203
											8,436							2,563														7,690		631	115				3,676
																		10,605																						25,921
13,338	3,269	3.27	16,471	1,070	151	10,471	207	622	1,235	11,653	8,436	2,006	720		867		28,301	45,785	203	1,166				2,994	1,457		116	5,141	13,851	10,960	11,653	11,362	7,690		822	2,197	28,301			63,460
							50.59	1,093	2,178				156	7.87	129		3,100	529	167	10.81						512						3,100					3,100			778
										2,899								41.83													2,827			47.60	24.87				52.97
										190								52.10													171			17.50	1.50				65.98
											2,998							963														2,733		224	40.99				1,247
																		256																						324
										11.40																														
							50.59	1,093	2,178	3,100	2,998		156	7.87	129		3,100	1,842	167	10.81						512						3,100	2,998	2,733		289	67.37	3,100			2,468
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,715	3,412	14,754	11,433	2,006	876	7.87	997		31,402	47,627	370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	14,359	10,423		1,111	2,265	31,402			65,928

Table A-175: Energy and material flow table for the UK iron and steel sector: site 1 - Int.wks (Base) and EAF wks (Base) [2007]

Mass	Main output			Energy inputs																			Energy outputs											
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt
Coke oven	Dry coke	kt	4,077	5,638												277	996				1,034			4,237	24.09	651					150		
Sinter plant	Sinter	kt	13,851					5.40							656	12.35					12.81													
Blast furnace	Hot metal	kt	10,960	1,242		201		48.81						3,910	490	74.41	6,206				3,700						22,701					315		
Basic oxygen furnace	Liquid steel	kt	11,653				0.15									21.24					193									316				
Electric arc furnace	Liquid steel	kt	3,100		9.37		0.04	11.53	0.20					22.92							33.92													
Continuous caster	Semi-finished steel	kt	14,188					11.81								1.38					7.95													
Ingot caster	Semi-finished steel	kt	171					3.22													3.70													
Hot rolling mill	Hot-rolled steel	kt	10,424					283								18.62	195			179	217											79.15		
Downstream and other	Finished steel	kt	4,646			6.20	0.31	172	4.26							18.06	816			138	709											80.07		
Power plant and Boiler						31.35		48.74								184	12,899				11,538											18,313		
Losses/flaring																35.19	1,589				1,337													
Sector	Crude steel	kt	14,392	6,881	9.37	239	0.50	584	4.46					3,933	1,146	642	22,701			316	18,787			4,237	24.09	651	22,701			316	150	18,787		

Material inputs																								Material outputs																					
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt
																	6,864	4,579																	277	6,864				5,575
11,300		3.27	4,071	925	151							1,949					3,117	12,513		984								4,071	13,851						90.22	3,117				14,536
1,944	3,269		12,400	145				2.71				57.27			334		8,998	21,998		18.76				2,994			116	1,070		10,960					1,556	8,998				12,647
93.35						10,471	207	620	1,235				720		820		9,323		203	164					1,457						11,653					58.27	9,323				901
							50.59	1,093	2,178				156	7.87	172		3,100	637	167	10.81						512						3,100						3,100				778
										14,555								247														14,191			239	125				260
										190								62.76														171			17.50	1.50				65.98
											11,435							4,037															10,424		855	156				4,712
								3.42			5,324							4,532															4,646		608	69.69				5,687
																		13,082																						26,245
																		1,574																						3,198
13,338	3,269	3.27	16,471	1,070	151	10,471	257	1,719	3,412	14,745	16,759	2,006	876	7.87	1,327		31,402	63,263	370	1,177				2,994	1,457	512	116	5,141	13,851	10,960	14,754	14,362	15,070		1,719	2,334	31,402			74,606

Summary	Total balance			
Process/system/site description	Total mass inputs	Total mass outputs	Net mass flow	% error in balance
Unit	kt	kt	kt	
Coke oven	19,388	18,812	576	3%
Sinter plant	35,699	35,678	21.03	0%
Blast furnace	65,042	64,742	299	0%
Basic oxygen furnace	24,070	23,901	169	1%
Electric arc furnace	7,651	7,524	126	2%
Continuous caster	14,823	14,823	0.00	0%
Ingot caster	260	260	0.00	0%
Hot rolling mill	16,365	16,365	0.00	0%
Downstream and other	11,723	11,720	3.42	0%
Power plant and Boiler	37,783	37,783	0.00	0%
Losses/flaring	4,535	4,535	0.00	0%
Sector	237,338	236,143	1,195	1%

Table A-176: Thermodynamic flow table for the 2007 UK iron and steel sector: Mass-flows

Temperature	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C	deg-C
Coke oven	Dry coke	kt	4,077																		180			1,100	1,100	900						
Sinter plant	Sinter	kt	13,851																		180												
Blast furnace	Hot metal	kt	10,960																		180						150				180		
Basic oxygen furnace	Liquid steel	kt	11,653																		180								1,672				
Electric arc furnace	Liquid steel	kt	3,100																		180												
Continuous caster	Semi-finished steel	kt	14,188																		180												
Ingot caster	Semi-finished steel	kt	171																		180												
Hot rolling mill	Hot-rolled steel	kt	10,424																		180										180		
Downstream and other	Finished steel	kt	4,646																		180										180		
Power plant and Boiler																					180										180		
Losses/flaring																					180										180		
Sector	Crude steel	kt	14,392																														

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Enthalpy of devaluation - Specific	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077	39.08												2.79	0.62							29.33	0.17	6.55					1.47		
Sinter plant	Sinter	kt	13,851					0.02							1.34	0.04																		
Blast furnace	Hot metal	kt	10,960	3.20		0.75		0.21						10.07	1.26	0.28	1.44										5.26							
Basic oxygen furnace	Liquid steel	kt	11,653				0.00									0.07														0.16			
Electric arc furnace	Liquid steel	kt	3,100		0.09		0.00	0.18	0.00					0.21																			
Continuous caster	Semi-finished steel	kt	14,188					0.04								0.00																	
Ingot caster	Semi-finished steel	kt	171					0.90																									
Hot rolling mill	Hot-rolled steel	kt	10,424					1.29								0.07	0.05			0.10													
Downstream and other	Finished steel	kt	4,646			0.05	0.00	1.77	0.04							0.16	0.45			0.17													
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	13.51	0.02	0.68	0.00	1.94	0.01					7.71	2.25	1.83	4.01			0.13				8.31	0.05	1.86	4.01			0.13	0.42		

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Thermal energy - Specific	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077																		0.70			1.68	0.01	0.57					0.13		
Sinter plant	Sinter	kt	13,851																		0.00												
Blast furnace	Hot metal	kt	10,960																		0.94						0.22					0.08	
Basic oxygen furnace	Liquid steel	kt	11,653																		0.05									0.06			
Electric arc furnace	Liquid steel	kt	3,100																		0.03												
Continuous caster	Semi-finished steel	kt	14,188																		0.00												
Ingot caster	Semi-finished steel	kt	171																		0.06												
Hot rolling mill	Hot-rolled steel	kt	10,424																		0.06											0.02	
Downstream and other	Finished steel	kt	4,646																		0.42											0.05	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392																		3.62			0.48	0.00	0.16	0.16			0.05	0.04	3.62	

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Total energy - Specific	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077	39.08												2.79	0.62				0.70	0.03	0.05	31.01	0.18	7.12					1.60		
Sinter plant	Sinter	kt	13,851					0.02							1.34	0.04					0.00	0.04	0.06										
Blast furnace	Hot metal	kt	10,960	3.20		0.75		0.21						10.07	1.26	0.28	1.44				0.94	0.06	0.10				5.48				0.08	0.03
Basic oxygen furnace	Liquid steel	kt	11,653				0.00									0.07					0.05	0.06	0.09							0.22			
Electric arc furnace	Liquid steel	kt	3,100		0.09		0.00	0.18	0.00					0.21							0.03		1.53										
Continuous caster	Semi-finished steel	kt	14,188					0.04						0.00							0.00	0.01	0.02										
Ingot caster	Semi-finished steel	kt	171					0.90													0.06		0.32										
Hot rolling mill	Hot-rolled steel	kt	10,424					1.29								0.07	0.05			0.10	0.06	0.10	0.25									0.02	
Downstream and other	Finished steel	kt	4,646			0.05	0.00	1.77	0.04							0.16	0.45			0.17	0.42	0.54	1.25									0.05	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	13.51	0.02	0.68	0.00	1.94	0.01					7.71	2.25	1.83	4.01			0.13	3.62	0.40	1.16	8.79	0.05	2.02	4.17			0.18	0.45	3.62	0.40

| Material inputs | | | | | | | | | | | | | | | | | | |

Std. chemical exergy - Specific	Main output			Energy inputs																		Energy outputs										
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077	42.60												2.79	0.61							31.09	0.18	6.55					1.57		
Sinter plant	Sinter	kt	13,851					0.02							1.42	0.04																		
Blast furnace	Hot metal	kt	10,960	3.49		0.80		0.22						10.68	1.34	0.28	1.41										5.16						
Basic oxygen furnace	Liquid steel	kt	11,653				0.00									0.07														0.16			
Electric arc furnace	Liquid steel	kt	3,100		0.10		0.00	0.18	0.00					0.22																			
Continuous caster	Semi-finished steel	kt	14,188					0.04								0.00																	
Ingot caster	Semi-finished steel	kt	171					0.94																									
Hot rolling mill	Hot-rolled steel	kt	10,424					1.35								0.07	0.05			0.10													
Downstream and other	Finished steel	kt	4,646			0.06	0.00	1.84	0.04							0.16	0.44			0.17													
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	14.73	0.02	0.73	0.00	2.02	0.01					8.18	2.38	1.83	3.93			0.13				8.81	0.05	1.86	3.93			0.13	0.45		

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Thermal exergy - Specific	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077																		0.62			0.78	0.00	0.30					0.07		
Sinter plant	Sinter	kt	13,851																		0.00												
Blast furnace	Hot metal	kt	10,960																		0.83						0.05				0.07		
Basic oxygen furnace	Liquid steel	kt	11,653																		0.04									0.04			
Electric arc furnace	Liquid steel	kt	3,100																		0.03												
Continuous caster	Semi-finished steel	kt	14,188																		0.00												
Ingot caster	Semi-finished steel	kt	171																		0.05												
Hot rolling mill	Hot-rolled steel	kt	10,424																		0.05										0.02		
Downstream and other	Finished steel	kt	4,646																		0.37										0.04		
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392																		3.20			0.22	0.00	0.08	0.03			0.03	0.02	3.20	

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Total exergy - Specific	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Coke oven	Dry coke	kt	4,077	42.60												2.79	0.61				0.62	0.03	0.05	31.87	0.18	6.85					1.64		
Sinter plant	Sinter	kt	13,851					0.02							1.42	0.04					0.00	0.04	0.06										
Blast furnace	Hot metal	kt	10,960	3.49		0.80		0.22						10.68	1.34	0.28	1.41				0.83	0.06	0.10				5.20					0.07	0.03
Basic oxygen furnace	Liquid steel	kt	11,653				0.00									0.07					0.04	0.06	0.09							0.20			
Electric arc furnace	Liquid steel	kt	3,100		0.10		0.00	0.18	0.00					0.22							0.03		1.53										
Continuous caster	Semi-finished steel	kt	14,188					0.04								0.00					0.00	0.01	0.02										
Ingot caster	Semi-finished steel	kt	171					0.94													0.05		0.32										
Hot rolling mill	Hot-rolled steel	kt	10,424					1.35								0.07	0.05			0.10	0.05	0.10	0.25									0.02	
Downstream and other	Finished steel	kt	4,646			0.06	0.00	1.84	0.04							0.16	0.44			0.17	0.37	0.54	1.25									0.04	
Power plant and Boiler																																	
Losses/flaring																																	
Sector	Crude steel	kt	14,392	14.73	0.02	0.73	0.00	2.02	0.01					8.18	2.38	1.83	3.93			0.13	3.20	0.40	1.16	9.03	0.05	1.94	3.96			0.16	0.46	3.20	0.40

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Enthalpy of devaluation - SFS System	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927	10,688												763	170							8,022	45.62	1,791					401		
Sinter plant	Sinter	kt	12,138					15.73							1,130	30.91																	
Blast furnace	Hot metal	kt	10,728	2,394		561		159						7,524	944	208	1,075										3,931						
Basic oxygen furnace	Liquid steel	kt	11,653				0.44									60.67														129			
Electric arc furnace	Liquid steel	kt	3,089		18.36		0.11	38.17	0.64					44.89																			
Continuous caster	SF steel	kt	14,188					39.26								3.94																	
Ingot caster	SF steel	kt	171					10.72																									
System	SF steel	kt	14,359	13,081	18.36	561	0.55	263	0.64					7,569	2,074	1,066	1,244							8,022	45.62	1,791	3,931			129	401		

| Material inputs | | | | | | | | | | | | | | | | | | |

Thermal energy - SFS system	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927																		192			460	2.61	155					35.62		
Sinter plant	Sinter	kt	12,138																		2.17												
Blast furnace	Hot metal	kt	10,728																		699						162					59.59	
Basic oxygen furnace	Liquid steel	kt	11,653																		37.34									47.45			
Electric arc furnace	Liquid steel	kt	3,089																		6.52												
Continuous caster	SF steel	kt	14,188																		1.54												
Ingot caster	SF steel	kt	171																		0.71												
System	SF steel	kt	14,359																		940			460	2.61	155	162			47.45	35.62	59.59	

Material inputs																										Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
																																								84.24
			82.81																								144	490												316
																								317			2.25			955						14.21				208
						865																			156						1,176					4.82				135
																										54.71					312									121
										1,355																					685				11.53	6.02				22.65
										17.69																					16.50				0.84	0.07				5.75
			82.81			865				1,373														317	156	54.71	2.25	144	490	955	1,488	701			12.37	25.12				894

Summary	Energy categroy			Material category			Total			Total - Absolute		
Process/system/site description	Input	Output	Net	Input	Output	Net	Input	Output	Net	Input	Output	Net
Unit	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	PJ	PJ	PJ
Coke oven	192	653	-461		84.24	-84.24	192	737	-545	0.75	2.90	-2.14
Sinter plant	2.17		2.17	82.81	951	-868	84.98	951	-866	1.03	11.54	-10.51
Blast furnace	699	221	478		1,497	-1,497	699	1,718	-1,019	7.50	18.43	-10.93
Basic oxygen furnace	37.34	47.45	-10.11	865	1,472	-608	902	1,520	-618	10.51	17.71	-7.20
Electric arc furnace	6.52		6.52		488	-488	6.52	488	-481	0.02	1.51	-1.49
Continuous caster	1.54		1.54	1,355	725	630	1,357	725	632	19.25	10.28	8.97
Ingot caster	0.71		0.71	17.69	23.16	-5.47	18.41	23.16	-4.76	0.00	0.00	0.00
System	940	922	17.94	2,320	5,240	-2,920	3,260	6,162	-2,902	46.81	88.48	-41.67

Table A-185: Thermodynamic flow table for the 2007 UK SFS system: Process specific thermal (sensible and latent) mass-flow energy

Total energy - SFS system	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927	10,688												763	170				192	7.74	12.40	8,481	48.23	1,947					437		
Sinter plant	Sinter	kt	12,138					15.73							1,130	30.91					2.17	31.89	51.04										
Blast furnace	Hot metal	kt	10,728	2,394		561		159						7,524	944	208	1,075				699	45.18	72.32				4,093					59.59	25.00
Basic oxygen furnace	Liquid steel	kt	11,653				0.44									60.67					37.34	47.71	76.36							176			
Electric arc furnace	Liquid steel	kt	3,089		18.36		0.11	38.17	0.64					44.89							6.52		329										
Continuous caster	SF steel	kt	14,188					39.26								3.94					1.54	10.57	23.77										
Ingot caster	SF steel	kt	171					10.72													0.71		3.85										
System	SF steel	kt	14,359	13,081	18.36	561	0.55	263	0.64					7,569	2,074	1,066	1,244				940	143	569	8,481	48.23	1,947	4,093			176	437	59.59	25.00

Material inputs																										Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishing s	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
																																				346				84.24
28.42		0.01	175	21.01	43.44							9.02								196								237	805							28.46				383
5.46	23.45		315	3.69				1.35				0.30								4.18				715			5.12	27.16		7,511						284				208
0.27						7,263	126	316	631				189						227	37.30					354						7,170						25.79				502
							30.80	555	1,108				40.81	17.72					187	2.45						124					1,901										121
										8,842																					7,924			133	50.98				22.65
										115																					104			9.77	0.61				5.75
34.15	23.45	0.01	490	24.70	43.44	7,263	157	873	1,739	8,957		9.31	230	17.72					413	240				715	354	124	5.12	264	805	7,511	9,071	8,027			143	735				1,327

Summary	Energy categroy			Material category			Total			Total - Absolute		
Process/system/site description	Input	Output	Net	Input	Output	Net	Input	Output	Net	Input	Output	Net
Unit	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	PJ	PJ	PJ
Coke oven	11,832	10,913	919		430	-430	11,832	11,343	489	46.46	44.54	1.92
Sinter plant	1,262		1,262	474	1,453	-979	1,735	1,453	283	21.06	17.63	3.43
Blast furnace	13,681	4,177	9,503	353	8,751	-8,398	14,034	12,928	1,106	151	139	11.86
Basic oxygen furnace	223	176	46.28	8,790	8,052	737	9,012	8,229	784	105	95.89	9.13
Electric arc furnace	438		438	1,942	2,146	-204	2,380	2,146	234	7.35	6.63	0.72
Continuous caster	79.07		79.07	8,842	8,131	711	8,921	8,131	790	127	115	11.21
Ingot caster	15.28		15.28	115	120	-4.44	131	120	10.84	0.02	0.02	0.00
System	27,529	15,266	12,263	20,515	29,082	-8,567	48,045	44,349	3,696	690	637	53.08

Table A-186: Thermodynamic flow table for the 2007 UK SFS system: Process specific mass-flow and electrical energies

Std. chemical exergy - SFS system	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927	11,650												763	166							8,503	48.35	1,791					430		
Sinter plant	Sinter	kt	12,138					16.36							1,198	30.91																	
Blast furnace	Hot metal	kt	10,728	2,609		600		165						7,976	1,000	208	1,053										3,852						
Basic oxygen furnace	Liquid steel	kt	11,653				0.47									60.67														129			
Electric arc furnace	Liquid steel	kt	3,089		21.49		0.12	39.70	0.67					47.59																			
Continuous caster	SF steel	kt	14,188					40.83								3.94																	
Ingot caster	SF steel	kt	171					11.15																									
System	SF steel	kt	14,359	14,259	21.49	600	0.59	273	0.67					8,023	2,198	1,066	1,219							8,503	48.35	1,791	3,852			129	430		

Material inputs																									Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
																		15.94																		369				54.66
59.12		0.00	74.72	16.97	47.47							24.98						39.63		155								74.72	254							25.93				149
11.36	29.65		254	2.98				1.23				0.82			2.83			77.82		3.30				248			2.39	21.94		6,118						264				149
0.56						5,971	118	287	573				115		7.09				211	29.40					123						5,445						19.11				367
							28.74	505	1,007				24.83	18.45	1.48			2.29	173	1.93						43.20					1,443											7.22
										6,801								0.89													6,580			111	40.96					2.43
										88.78								0.23													79.29			8.11	0.49					0.62
71.04	29.65	0.00	329	19.95	47.47	5,971	147	793	1,580	6,890		25.80	140	18.45	11.40			137	384	189				248	123	43.20	2.39	96.66	254	6,118	6,889	6,659			119	720				729

Summary	Energy categroy			Material category			Total			Total - Absolute		
Process/system/site description	Input	Output	Net	Input	Output	Net	Input	Output	Net	Input	Output	Net
Unit	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	PJ	PJ	PJ
Coke oven	12,579	10,773	1,806	15.94	424	-408	12,594	11,196	1,398	49.46	43.96	5.49
Sinter plant	1,245		1,245	418	503	-85.83	1,663	503	1,159	20.18	6.11	14.07
Blast furnace	13,611	3,852	9,759	384	6,803	-6,419	13,996	10,656	3,340	150	114	35.83
Basic oxygen furnace	61.14	129	-67.64	7,313	5,955	1,358	7,374	6,084	1,290	85.93	70.89	15.03
Electric arc furnace	110		110	1,763	1,494	269	1,873	1,494	379	5.79	4.61	1.17
Continuous caster	44.77		44.77	6,802	6,734	67.90	6,847	6,734	113	97.15	95.55	1.60
Ingot caster	11.15		11.15	89.01	88.51	0.50	100	88.51	11.65	0.02	0.02	0.00
System	27,662	14,754	12,908	16,785	22,002	-5,217	44,446	36,756	7,691	638	528	110

Table A-187: Thermodynamic flow table for the 2007 UK SFS system: Process specific standard chemical exergy of mass-flows

Thermal exergy - SFS system	Main output			Energy inputs																			Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927																		170			213	1.21	81.39					18.69		
Sinter plant	Sinter	kt	12,138																		1.92												
Blast furnace	Hot metal	kt	10,728																		619						34.25					52.75	
Basic oxygen furnace	Liquid steel	kt	11,653																		33.05									29.56			
Electric arc furnace	Liquid steel	kt	3,089																		5.78												
Continuous caster	SF steel	kt	14,188																		1.36												
Ingot caster	SF steel	kt	171																		0.63												
System	SF steel	kt	14,359																		832			213	1.21	81.39	34.25			29.56	18.69	52.75	

| Material inputs | | | | | | | | | | | | | | | | | | | | | | | | | | | Material outputs | | | | | | | | | | | | | | | | | | |

Total exergy - SFS system	Main output			Energy inputs																		Energy outputs									
Process/system/site description	Description	Unit	Output	Coking or injection coal	Coal	Fuel oil	Gas and diesel oil	Natural gas	Butane, propane and other	Carrier gas coal	Biomass mix (for syngas)	Charcoal	H_2	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Steam (internal)	Electricity (autogen.)	Electricity (grid)	Coke	Coke breeze	Coke oven gas	Blast furnace gas	TGR-BF process gas	Excess syngas	Basic oxygen furnace gas	Benzole and Tars	Steam (internal)	Electricity (autogen.)
Flow ID				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Unit				MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
Coke oven	Dry coke	kt	3,927	11,650												763	166				170	7.74	12.40	8,716	49.57	1,873					449		
Sinter plant	Sinter	kt	12,138					16.36							1,198	30.91					1.92	31.89	51.04										
Blast furnace	Hot metal	kt	10,728	2,609		600		165						7,976	1,000	208	1,053				619	45.18	72.32				3,887					52.75	25.00
Basic oxygen furnace	Liquid steel	kt	11,653				0.47									60.67					33.05	47.71	76.36							158			
Electric arc furnace	Liquid steel	kt	3,089		21.49		0.12	39.70	0.67					47.59							5.78		329										
Continuous caster	SF steel	kt	14,188					40.83								3.94					1.36	10.57	23.77										
Ingot caster	SF steel	kt	171					11.15													0.63		3.85										
System	SF steel	kt	14,359	14,259	21.49	600	0.59	273	0.67					8,023	2,198	1,066	1,219				832	143	569	8,716	49.57	1,873	3,887			158	449	52.75	25.00

Material inputs																								Material outputs																	
Iron ore	Iron ore Pellets	Mn ore	Sinter	BF Sinter returns	Flue dust and sludge	Hot metal	Cold iron	Metal scrap (internal)	Metal scrap (purchased)	Liquid steel	SF steel	Limestone and dolomite	Lime and calcined dolomite	Electrodes	O_2	N_2	Process/ cooling water	Air	Finishings	Slag, scale, other Fe bearing	Direct reduced iron	MEA /MDEA make-up	Sodium hydroxide	BF/iron-making slag	BOF slag	EAF slag	BF flue dust	Sinter return	Sinter	Hot metal	Liquid steel	SF steel	Hot-rolled steel	Direct reduced iron	Scrap	Other	Process/ cooling water	O_2	CO_2 (captured)	Flue gas
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs
																		15.94																		369				73.54
59.12		0.00	97.43	16.97	47.47							24.98						39.63		155								140	477							25.93				243
11.36	29.65		254	2.98				1.23				0.82			2.83			77.82		3.30				439			3.98	21.94		6,771						266				197
0.56						6,563	118	287	573				115		7.09				211	29.40					220						6,247						22.06				451
							28.74	505	1,007				24.83	18.45	1.48			2.29	173	1.93						76.97					1,656											82.24
										7,708								0.89														6,967			117	44.36				13.96
										101								0.23														88.60			8.59	0.53				3.54
71.04	29.65	0.00	352	19.95	47.47	6,563	147	793	1,580	7,809		25.80	140	18.45	11.40			137	384	189				439	220	76.97	3.98	162	477	6,771	7,904	7,055			126	728				1,065

Summary	Energy categroy			Material category			Total			Total - Absolute		
Process/system/site description	Input	Output	Net	Input	Output	Net	Input	Output	Net	Input	Output	Net
Unit	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	MJ/tsfs	PJ	PJ	PJ
Coke oven	12,769	11,087	1,681	15.94	442	-427	12,785	11,530	1,255	50.20	45.27	4.93
Sinter plant	1,330		1,330	440	886	-446	1,770	886	884	21.49	10.76	10.73
Blast furnace	14,348	3,964	10,383	384	7,699	-7,315	14,732	11,664	3,068	158	125	32.92
Basic oxygen furnace	218	158	59.91	7,904	6,941	963	8,122	7,099	1,023	94.65	82.73	11.92
Electric arc furnace	444		444	1,763	1,815	-52.11	2,208	1,815	392	6.82	5.61	1.21
Continuous caster	80.47		80.47	7,709	7,142	567	7,790	7,142	647	111	101	9.19
Ingot caster	15.62		15.62	101	101	-0.42	116	101	15.21	0.02	0.02	0.00
System	29,205	15,210	13,995	18,318	25,028	-6,710	47,523	40,238	7,285	682	578	105

Table A-189: Thermodynamic flow table for the 2007 UK SFS system: Process specific mass-flow and electrical exergies

Process plant	Waste streams				Other			Total
	Chem. (h_{ch})	Thermal (h_{th})			Total	Misc.	Q	
		Total	Product	Exhaust				
Coke oven	1.26	2.70	1.69	0.31	1.79	0.83	0.95	5.75
Sinter plant	0.11	1.03	0.58	0.37	0.33	0.00	0.33	1.47
Blast furnace	0.36	1.03	0.09	0.28	1.48	0.20	1.28	2.87
Basic oxygen furnace	0.62	0.54	0.11	0.17	0.97	0.00	0.97	2.12
Electric arc furnace	0.32	0.93	0.11	0.56	1.09	0.38	0.71	2.34
Continuous casting	0.00	0.73	0.69	0.02	0.80	0.26	0.54	1.53
Ingot casting	0.00	1.94	1.39	0.48	0.91	0.35	0.56	2.86
Hot rolling	0.00	1.10	0.55	0.50	0.83	0.00	0.83	1.94
All processes	1.26	2.70	1.69	0.31	1.79	0.83	0.95	5.75

Table A-190: Breakdown of energy losses from UK iron and steel process plant, GJ/t process output

Process plant	Waste streams				Other			Total
	Chem. (b_{ch})	Thermal (b_{th})			Total	Q^b	b_d	
		All	Product	Exhaust				
Coke oven	1.55	1.22	0.78	0.07	4.59	0.63	3.39	7.36
Sinter plant	0.21	0.43	0.26	0.11	1.05	0.24	0.81	1.68
Blast furnace	0.55	0.43	0.06	0.06	4.11	0.96	3.14	5.09
Basic oxygen furnace	0.55	0.36	0.09	0.10	1.26	0.74	0.52	2.17
Electric arc furnace	0.23	0.60	0.09	0.35	1.82	0.54	1.28	2.66
Continuous casting	0.00	0.41	0.39	0.01	0.66	0.40	0.25	1.07
Ingot casting	0.05	1.07	0.78	0.25	1.28	0.42	0.85	2.40
Hot rolling	0.06	0.50	0.23	0.24	1.44	0.57	0.87	2.00
All processes	1.55	1.22	0.78	0.07	4.59	0.63	3.39	7.36

Table A-191: Breakdown of exergy losses from UK iron and steel process plant, GJ/t process output

A6 The cement sector

A6.1 Technology roadmap projection model

The resource balances of processes were incorporated into a flexible projection model so that key variables are brought into control. The model was built in built in Microsoft Excel. Figure A-32 is a screenshot of the control interface for selected variables.

Variable	Input	Suggested	Unit /choice	Notes
Biomass C-fix?	Y	Y	Y/N	
NCV?	Y	Y	Y/N	NCV or GCV
Capture efficiencies				
MEA Post-comb.	85%	85%	%	
MEA post-comb. over-the-fence-steam	85%	85%	%	
KS-1 Post-comb.	85%	85%	%	
Oxyfuel (PC only)	62%	62%	%	
Oxyfuel (PC only) - colocation	62%	62%	%	
Oxyfuel comb.	95%	95%	%	
Oxyfuel comb. - colocation	95%	95%	%	
CCS proportion for Aether	0%		%	Additional to un-sequestered Aether production

Figure A-32: Screenshot of cement technology projection model variable control interface

Figure A-33 displays the interface enabling the construction of roadmaps at 5 year intervals to 2050. The model, and projection analysis, begins at the base year 2010 from which site share and aggregate production has been updated annually to 2013. Cells shaded in grey are editable but this is not suggested for the generation of roadmaps as they reflect assumed technological unavailability or years past. Roadmaps constructed in the model for the assessment in section 5.4 are shown in Figure A-34.

Alternative cements and CCS are treated in the roadmap construction interface as mutually exclusive options. If the combined uptake of either technological group summates to over 100%, the model responds with a warning message box and user must re-input the figures. Where Aether is combined with CCS, this is controlled separately from the variable control interface. Thus total Aether production is the non-sequestered uptake in the roadmap construction interface plus the product of total CCS uptake in that interface and the proportion of that CCS specified for Aether production.

Cement roadmap design interface																																
Year	Dry kiln modification			Clinker sub.	Fuel substitution				Kiln substitution						Cement site retrofit/substitution							Alt. clinker		Cement substitution		External		
					Kiln		CHP	Other process	1 (base)	2 (base)	3 (base)	1k (for 2/3)	2k (for 2/3)	3k (for 1)	1c	2c	3c	4c	5c	6c	7c	1a	2a	3a	4a			
	Grate cooler	PC	PH (4-6)	PFA/ GGBS blend	Alternative waste fuels - total	Alternative waste fuels - biomass	Coal-to-biomass	Biomass	Dry rotary kiln	Semi-dry rotary kiln	Semi-wet rotary kiln	BPT: Dry rotary kiln - 5 stage PH + PC	BAT: Dry rotary kiln - 6 stage PH + PC	Fluidised bed kiln	MEA post-comb. CCS	MEA post-comb. CCS; over-the-fence	KS-1 post-comb. CCS	Oxyfuel CCS (PC only)	Oxyfuel CCS (PC only) - colocation	Oxyfuel CCS	Oxyfuel CCS - colocation	Aether	Celitement	Geo-polymer	Novacem	Grid primary energy intensity change	Grid decarbonisation	2010 prod.
2010	75%	72%	17%	27%	40%	9%	0%	8%	75%	12%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
2011	75%	72%	17%	27%	41%	10%	0%	9%	76%	11%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	107%
2012	75%	72%	17%	28%	41%	10%	0%	9%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	100%
2013	75%	72%	17%	29%	41%	10%	0%	9%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	103%
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	11%	112%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	24%	112%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	45%	112%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%	61%	112%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	68%	112%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	74%	112%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	12%	80%	112%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	85%	112%

Figure A-33: Screenshot of cement technology projection model roadmap construction interface

Year	Dry kiln modification			Clinker sub.	Fuel substitution				Kiln substitution						Cement site retrofit/substitution								Alt. clinker	Cement substitution		
					Kiln		CHP	Other process	1	2	3	1k	2k	3k	1c	2c	3c	4c	5c	6c	7c		1a	2a	3a	4a
	Grate cooler	PC	PH (4-6)	PFA/ GGBS blend	Alternative fuels - total	Alternative fuels - biomass	Coal-to-biomass	Biomass	Dry rotary kiln	Semi-dry rotary kiln	Semi-wet rotary kiln	BPT: Dry rotary kiln - 5 stage	BAT: Dry rotary kiln - 6 stage	Fluidised bed kiln	MEA post-comb. CCS	MEA post-comb. CCS; over-the-	KS-1 post-comb. CCS	Oxyfuel CCS (PC only)	Oxyfuel CCS (PC only) - colocati	Oxyfuel CCS	Oxyfuel CCS - colocation		Aether	Celitement	Geo-polymer	Novacem
BASE																										
2015	75%	72%	17%	29%	41%	10%	0%	9%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	75%	72%	17%	29%	41%	10%	0%	9%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	75%	72%	17%	29%	41%	10%	0%	9%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	75%	72%	17%	29%	41%	10%	0%	14%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	75%	72%	17%	29%	41%	10%	0%	14%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	72%	17%	29%	41%	10%	0%	14%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	75%	72%	17%	29%	41%	10%	0%	14%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	75%	72%	17%	29%	41%	10%	0%	14%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BASELINE																										
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	38%	13%	0%	12%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	31%	39%	15%	0%	14%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	32%	39%	17%	0%	23%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	33%	39%	19%	0%	26%	76%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	34%	40%	21%	0%	29%	76%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	34%	40%	23%	0%	31%	76%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	35%	66%	25%	0%	34%	76%	0%	0%	24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA	Reasonable action																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS	Reasonable action with CCS (1c)																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS2	Reasonable action with CCS (2c)																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS3	Reasonable action with CCS (3c)																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	0%	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS4	Reasonable action with CCS (4c)																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	0%	0%	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS5	Reasonable action with CCS (5c)																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	40%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%
FFT	Fuel and feedstock transition																									
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	32%	59%	20%	0%	18%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	34%	76%	29%	0%	27%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	36%	88%	38%	0%	53%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	39%	99%	48%	0%	65%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	100%	100%	50%	41%	107%	57%	0%	77%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	100%	100%	60%	43%	114%	66%	0%	90%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	100%	75%	45%	90%	75%	0%	100%	76%	0%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure A-34: Screenshot of cement technology projection model roadmap designs

Year	Dry kiln modification			Clinker sub.	Fuel substitution				Kiln substitution						Cement site retrofit/substitution							Alt. clinker	Cement substitution		
					Kiln		CHP	Other process	1 (base)	2 (base)	3 (base)	1k (for 2/3)	2k (for 2/3)	3k (for 1)	1c	2c	3c	4c	5c	6c	7c	1a	2a	3a	4a
	Grate cooler	PC	PH (4-6)	PFA/ GGBS blend	Alternative waste fuels - total	Alternative waste fuels - biomas	Coal-to-biomass	Biomass	Dry rotary kiln	Semi-dry rotary kiln	Semi-wet rotary kiln	BPT: Dry rotary kiln - 5 stage	BAT: Dry rotary kiln - 6 stage	Fluidised bed kiln	MEA post-comb. CCS	MEA post-comb. CCS; over-the-	KS-1 post-comb. CCS	Oxyfuel CCS (PC only)	Oxyfuel CCS (PC only) - colocation	Oxyfuel CCS	Oxyfuel CCS - colocation	Aether	Celitement	Geo-polymer	Novacem
RT	Shared uptake																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	9%	2%	2%	2%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	18%	4%	4%	4%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	27%	7%	7%	7%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	33%	10%	10%	10%
RT2	Aether transition																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	32%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%
RT2-CCS	Aether with CCS														*60% CCS aether*										
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	10%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	25%	0%	0%	0%	0%	0%	0%	20%	0%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	40%	0%	0%	0%	0%	0%	0%	35%	0%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	50%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%
RT3	Celitement transition																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	0%	28%	0%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%	0%
RT4	Geopolymer transition																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%	0%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	28%	0%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%
RT5	Novacem transition																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	31%	49%	17%	0%	15%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	33%	57%	22%	0%	20%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	34%	64%	28%	0%	38%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	36%	69%	33%	0%	45%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%
2040	100%	100%	50%	37%	73%	39%	0%	53%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	16%
2045	100%	100%	60%	39%	77%	44%	0%	61%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	28%
2050	100%	100%	75%	40%	80%	50%	0%	68%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	40%
FFT/RT2	Fuel and feedstock transition with Aether transition																								
2015	75%	72%	17%	30%	38%	11%	0%	10%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	100%	88%	36%	32%	59%	20%	0%	18%	76%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	100%	94%	44%	34%	76%	29%	0%	27%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	100%	100%	50%	36%	88%	38%	0%	53%	76%	0%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	100%	100%	50%	39%	99%	48%	0%	65%	71%	0%	0%	12%	12%	5%	0%	0%	0%	0%	0%	0%	0%	16%	0%	0%	0%
2040	100%	100%	50%	41%	107%	57%	0%	77%	65%	0%	0%	12%	12%	11%	0%	0%	0%	0%	0%	0%	0%	32%	0%	0%	0%
2045	100%	100%	60%	43%	114%	66%	0%	90%	59%	0%	0%	12%	12%	17%	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%
2050	100%	100%	75%	45%	90%	75%	0%	100%	56%	0%	0%	12%	12%	20%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%

Figure A- cont'd: Screenshot of cement technology projection model variable control interface

A6.1.1 Other model outputs

The following outputs supplement the assessment outputs of chapter 5.

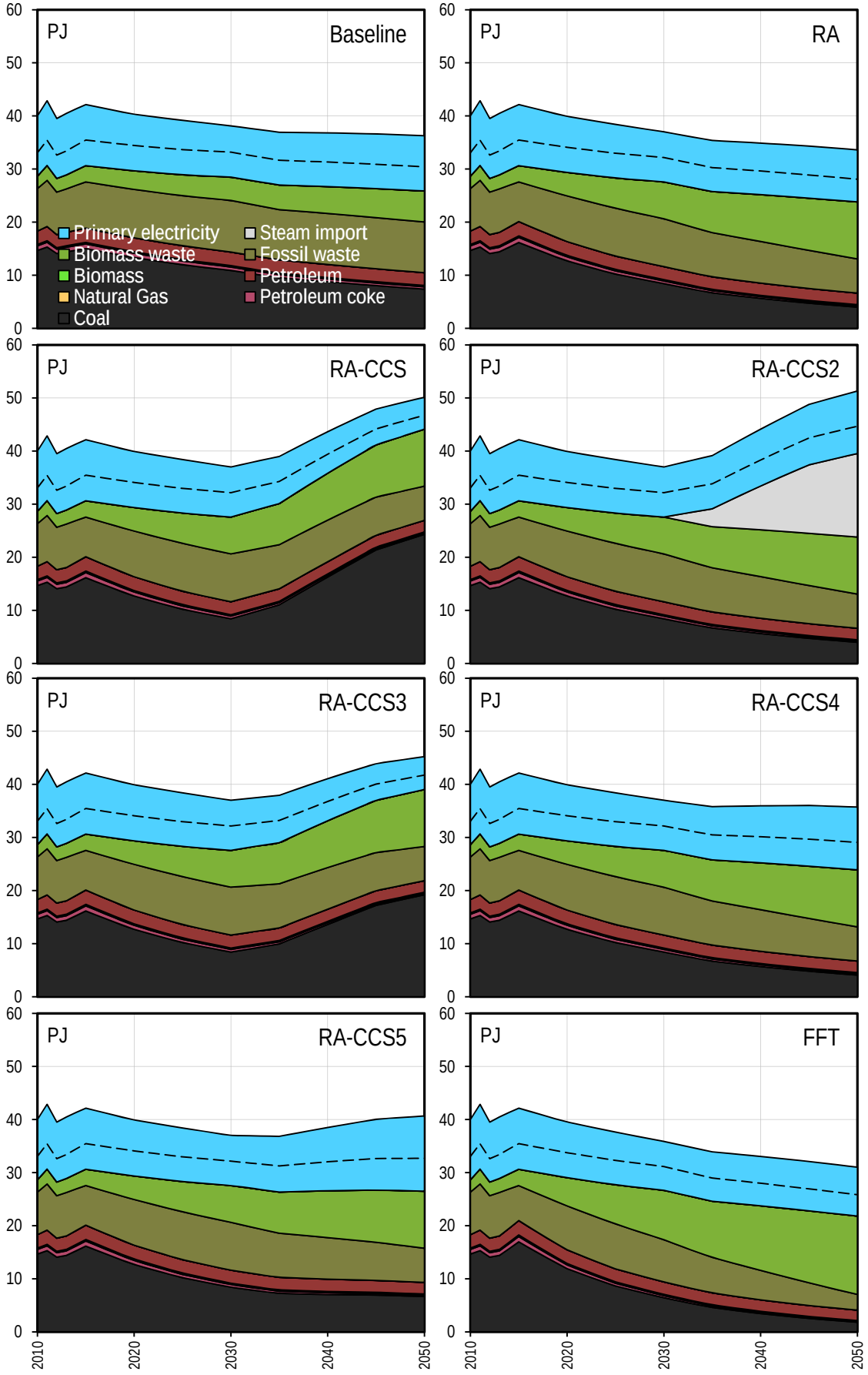

Figure A-35: Energy splits of technology roadmaps of the UK cement sector

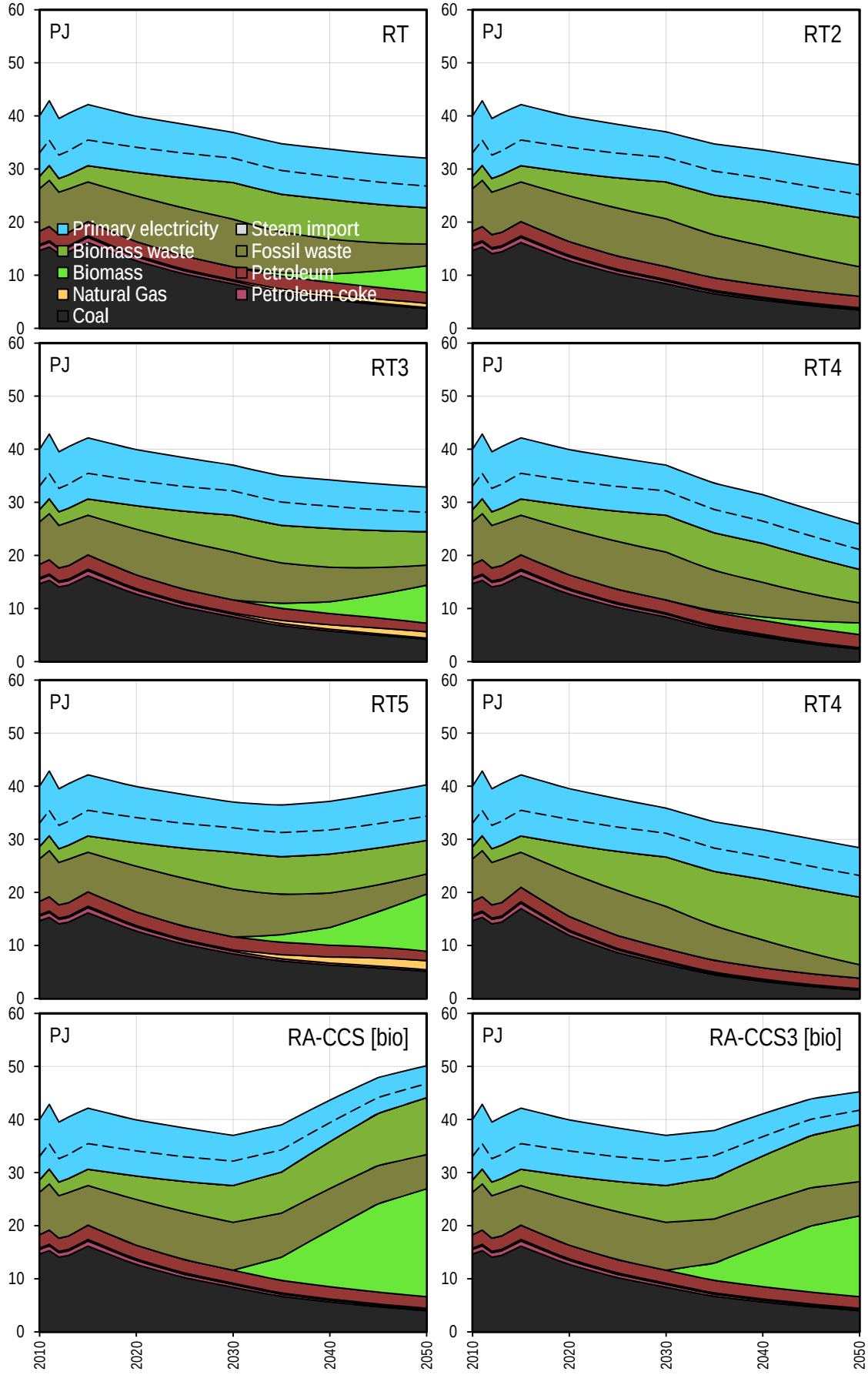

Figure A-cont'd: Energy splits of technology roadmaps of the UK cement sector

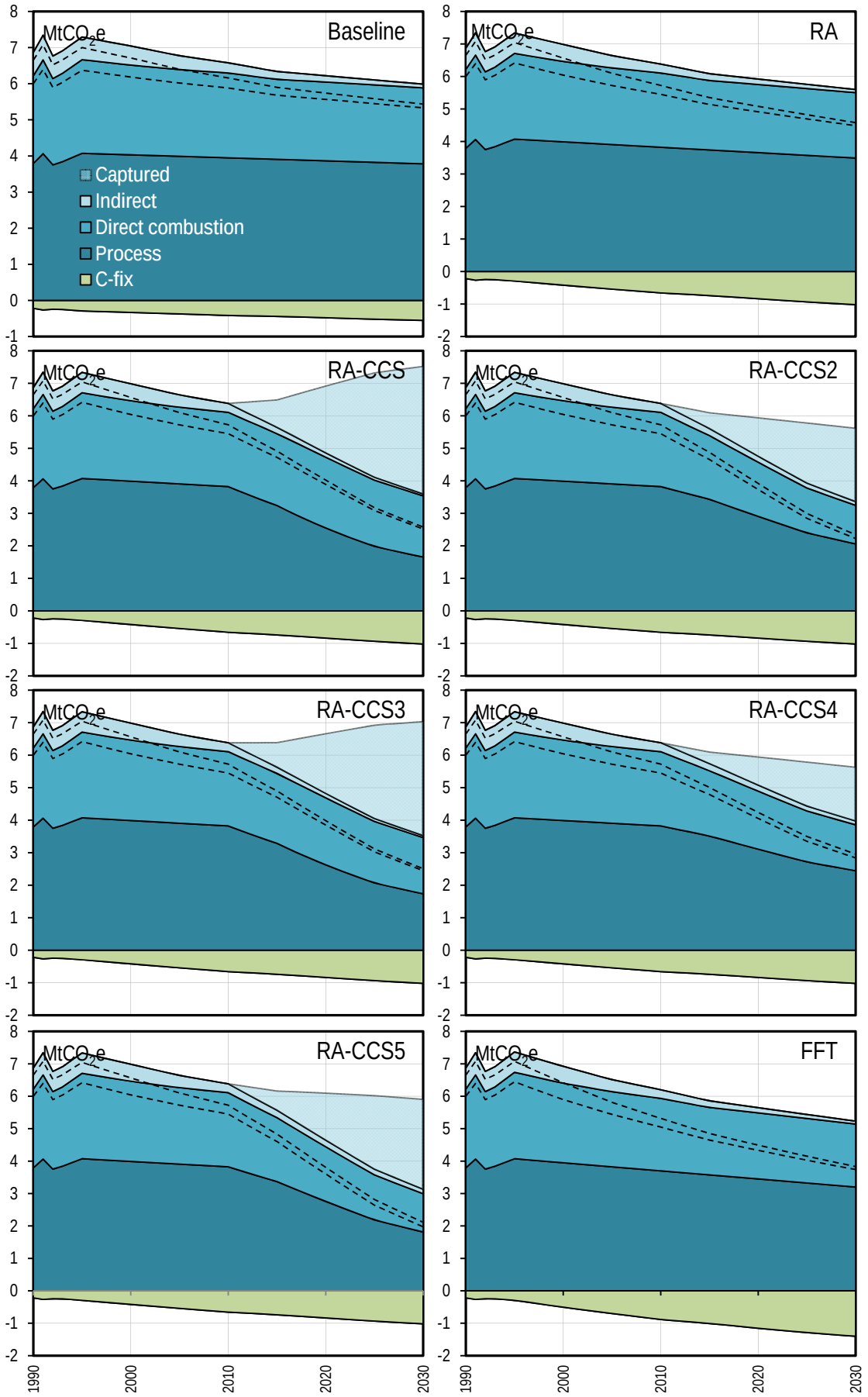

Figure A-36: GhG emission splits of technology roadmaps of the UK cement sector

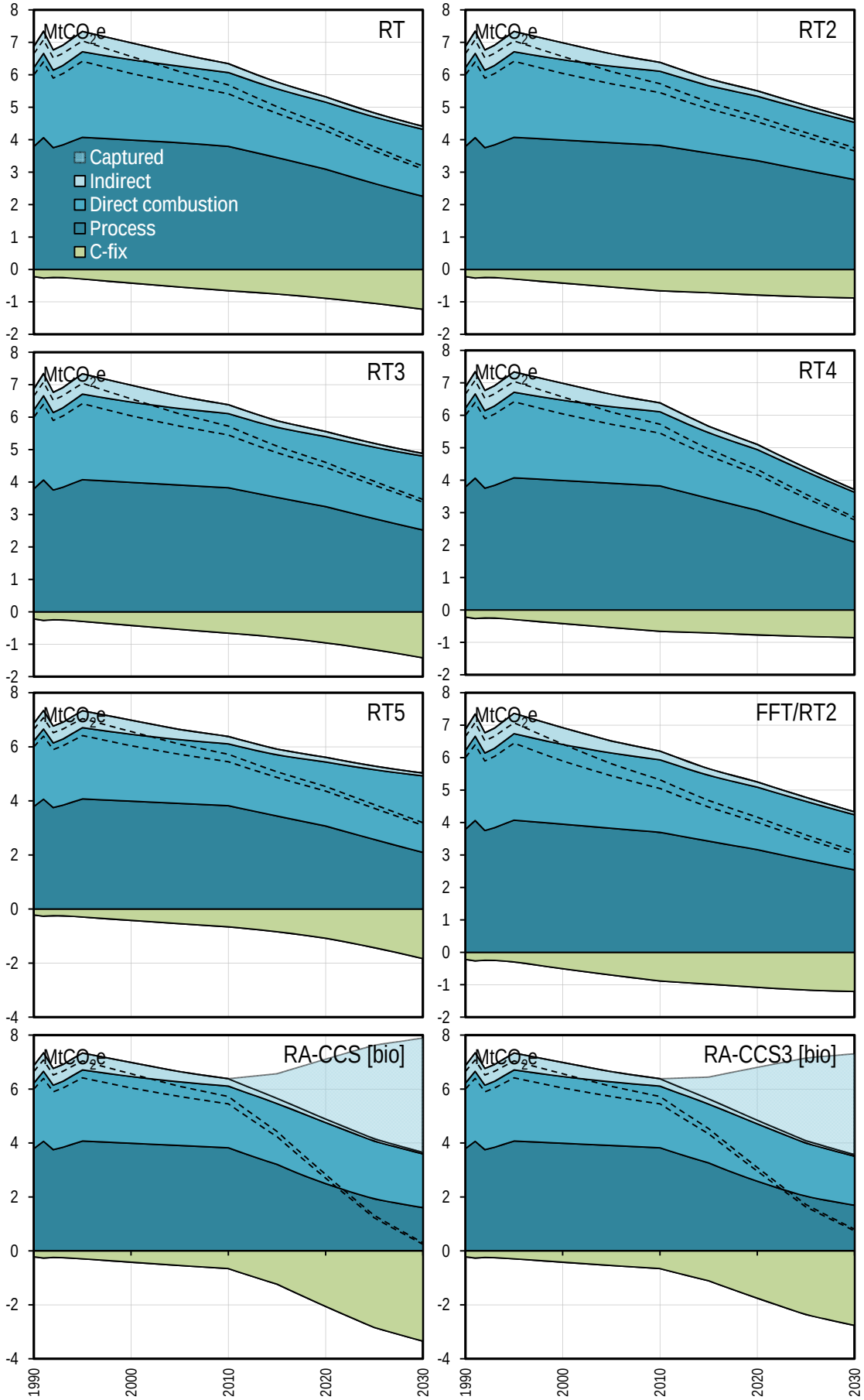

Figure A-cont'd: GhG emission splits of technology roadmaps of the UK cement sector

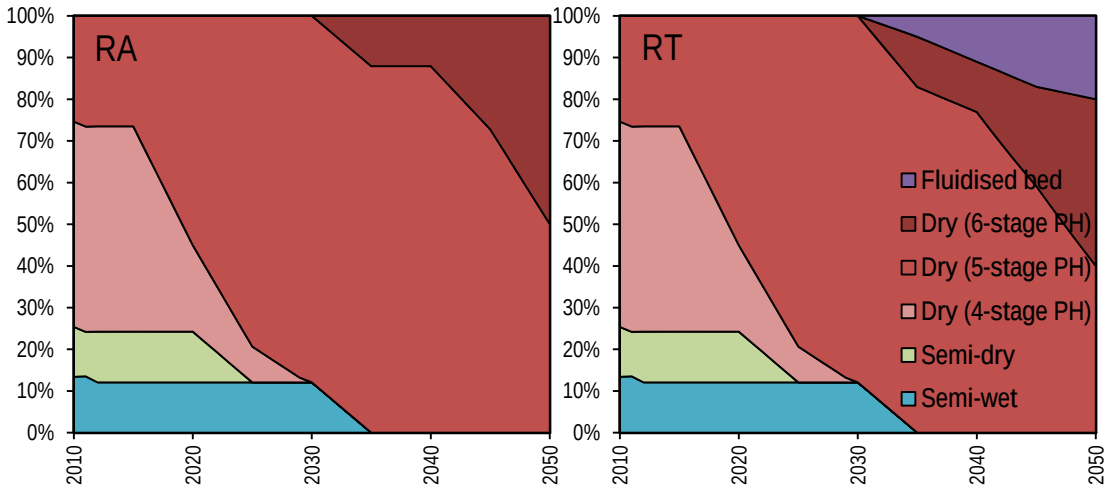

Figure A-37: Rotary kiln capacity share in technology roadmap groups of the UK cement sector

Calorific values	Energy inputs											Energy outputs	
Resource	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Note/Source	IEAGHG 2008	IEAGHG 2008	AEA 2012a	AEA 2012a	Ulcored paper	AEA 2012b; Calc	AEA 2012b; Calc	Steam tables	Calculated	Standard	Standard	Calculated	Standard
Unit	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/GWh	PJ/GWh	PJ/kt	PJ/GWh
NCV	0.0257	0.0342	0.0477	0.0430	0.0127	0.0224	0.0224	0.0027	0.0027	0.0036	0.0036	0.0027	0.0036
GCV	0.0271	0.0360	0.0530	0.0453	0.0141	0.0248	0.0248	0.0027	0.0027	0.0036	0.0036	0.0027	0.0036

Emissions factors	Energy inputs											Energy outputs	
Resource	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated) - credit	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Note/Source	AEA 2012b	AEA 2012b	AEA 2012	AEA 2012	AEA 2012	AEA 2012b; Calc	AEA 2012	Calculated	See note	AEA 2012	AEA 2012	See note	See note on auto
Unit	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ	kteCO2/PJ
GhG (per unit NCV)	96.5	96.0	57.2	81.2	0	61.3	0.0	0.0	0.0	144.5	144.5	0.0	144.5
CO2 (per unit NCV)	94.5	94.0	57.0	74.2	0	61.1	0.0	0.0	0.0	143.6	143.6	0.0	143.6

Figure A-38: General energy and emissions conversion factors used for analysis of the UK cement sector

Mass and elec. units - 2010 baseline	Main output		Energy inputs											Energy outputs	
Process/system/site description	Output description	Output, kt	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Unit		kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	GWh	GWh	kt	GWh
Rotary kiln	Clinker	6,843	571	25.34	0.45	4.76		358	103				161		
Rotary kiln with planetary cooling	Clinker	1,294	105	4.64	0.083	0.87		65.67	18.88				30.46		
Dry rotary kiln with 4-stage PH	Clinker	1,447	120	5.35	0.096	1.00		75.64	21.75				34.08		
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	144	6.39	0.11	1.20		90.40	25.99				45.28		
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	129	5.73	0.10	1.08		80.97	23.28				40.89		
Semi-wet rotary kiln	Clinker	919	96.29	4.28	0.077	0.80		60.45	17.38				21.63		
Semi-dry rotary kiln	Clinker	818	66.74	2.96	0.053	0.56		41.90	12.05				19.26		
Dry rotary kiln	Clinker	5,106	408	18.10	0.32	3.40		256	73.60				120		
Onsite grinding and mixing	Factory cement	8,012											786		
Cement plant (inc. other)	Factory cement	8,012	571	25.34	0.45	4.76		358	103				947		
Offsite grinding and mixing	Cement	1,389											143		
Other					5.12	53.63									
Sector	Cement	9,401	571	25.34	5.58	58.39		358	103				1,091		

Mass and elec. units - 2010 baseline	Main output		Material inputs											Material outputs			
Process/system/site description	Output description	Output, kt	Limestone	Limestone (to cement)	Clinker	Gypsum	PFA and puzzolana	GGBFS	Other	Quartz	Olivine (or serpentine)	Alkaline activating solution	O_2	Clinker	Cement (inc. substitutes)	O_2	CO_2 (captured)
Unit		kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt
Rotary kiln	Clinker	6,843	8,618											6,843			
Rotary kiln with planetary cooling	Clinker	1,294	1,629											1,294			
Dry rotary kiln with 4-stage PH	Clinker	1,447	1,823											1,447			
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	2,422											1,923			
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	2,187											1,737			
Semi-wet rotary kiln	Clinker	919	1,157											919			
Semi-dry rotary kiln	Clinker	818	1,030											818			
Dry rotary kiln	Clinker	5,106	6,431											5,106			
Onsite grinding and mixing	Factory cement	8,012		381	6,843	382	400	0.00	5.56						8,012		
Cement plant (inc. other)	Factory cement	8,012	8,618	381	6,843	382	400		5.56					6,843	8,012		
Offsite grinding and mixing	Cement	1,389					38.53	1,316	34.84						1,389		
Other																	
Sector	Cement	9,401	8,618	381	6,843	382	438	1,316	40.40					6,843	9,401		

Figure A-39: Energy and material data table for the UK cement sector: 2010 baseline, mass and electricity units

NCV - 2010 baseline	Main output		Energy inputs											Energy outputs	
Process/system/site description	Output description	Output, kt	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Unit		kt	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Rotary kiln	Clinker	6,843	14.67	0.87	0.022	0.20		8.01	2.30				0.58		
Rotary kiln with planetary cooling	Clinker	1,294	2.69	0.16	0.004	0.038		1.47	0.42				0.11		
Dry rotary kiln with 4-stage PH	Clinker	1,447	3.10	0.18	0.005	0.043		1.69	0.49				0.12		
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	3.70	0.22	0.005	0.052		2.02	0.58				0.16		
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	3.32	0.20	0.005	0.046		1.81	0.52				0.15		
Semi-wet rotary kiln	Clinker	919	2.48	0.15	0.004	0.035		1.35	0.39				0.078		
Semi-dry rotary kiln	Clinker	818	1.72	0.10	0.003	0.024		0.94	0.27				0.069		
Dry rotary kiln	Clinker	5,106	10.48	0.62	0.015	0.15		5.72	1.65				0.43		
Onsite grinding and mixing	Factory cement	8,012											2.83		
Cement plant (inc. other)	Factory cement	8,012	14.67	0.87	0.27	2.51		8.01	2.30				3.41		
Offsite grinding and mixing	Cement	1,389											0.52		
Other					0.24	2.31									
Sector	Cement	9,401	14.67	0.87	0.27	2.51		8.01	2.30				3.93		

Totals	Main output		Energy		SEC		GhG					Specific GhG				
Process/system/site description	Output description	Output, kt	Direct fuels	Total	Direct fuels	Total	Direct comb'	Indirect comb'	Total comb'	Process	Total	Direct comb'	Indirect comb'	Total comb'	Process	Total
Unit		kt	PJ	PJ	GJ/t	GJ/t	$ktCO_2e$	$ktCO_2e$	$ktCO_2e$	$ktCO_2e$	$ktCO_2e$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$	$kgCO_2e/t$
Rotary kiln	Clinker	6,843	26.08	26.66	3.81	3.90	2,007	83.85	2,091	3,792	5,883	293	12.25	306	554	860
Rotary kiln with planetary cooling	Clinker	1,294	4.78	4.89	3.70	3.78	368	15.85	384	717	1,101	284	12.25	297	554	851
Dry rotary kiln with 4-stage PH	Clinker	1,447	5.51	5.63	3.80	3.89	424	17.73	441	802	1,243	293	12.25	305	554	859
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	6.58	6.74	3.42	3.51	506	23.56	530	1,066	1,596	263	12.25	276	554	830
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	5.89	6.04	3.39	3.48	454	21.28	475	962	1,437	261	12.25	273	554	828
Semi-wet rotary kiln	Clinker	919	4.40	4.48	4.79	4.87	339	11.26	350	509	859	369	12.25	381	554	935
Semi-dry rotary kiln	Clinker	818	3.05	3.12	3.73	3.81	235	10.02	245	453	698	287	12.25	299	554	853
Dry rotary kiln	Clinker	5,106	18.63	19.06	3.65	3.73	1,434	62.57	1,496	2,830	4,326	281	12.25	293	554	847
Onsite grinding and mixing	Factory cement	8,012		2.83		0.35		409	409		409		51.06	51.06		51.06
Cement plant (inc. other)	Factory cement	8,012	28.63		3.57		2,208	493	2,701	3,792	6,493	276	61.53	337	473	810
Offsite grinding and mixing	Cement	1,389		0.52		0.37		74.52	74.52		74.52		53.63	53.63		53.63
Other			2.55				201		201		201					
Sector	Cement	9,401	28.63	32.56	3.05	3.46	2,208	567	2,776	3,792	6,568	235	60.36	295	403	699

Figure A-40: Energy and material data table for the UK cement sector: 2010 baseline, NCV

GCV - 2010 baseline	Main output		Energy inputs											Energy outputs	
Process/system/site description	Output description	Output, kt	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Unit		kt	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	GJ/t	GJ/t
Rotary kiln	Clinker	6,843	15.44	0.91	0.024	0.22		8.90	2.56				0.58		
Rotary kiln with planetary cooling	Clinker	1,294	2.83	0.17	0.004	0.039		1.63	0.47				0.11		
Dry rotary kiln with 4-stage PH	Clinker	1,447	3.26	0.19	0.005	0.045		1.88	0.54				0.12		
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	3.90	0.23	0.006	0.054		2.25	0.65				0.16		
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	3.49	0.21	0.005	0.049		2.01	0.58				0.15		
Semi-wet rotary kiln	Clinker	919	2.61	0.15	0.004	0.036		1.50	0.43				0.078		
Semi-dry rotary kiln	Clinker	818	1.81	0.11	0.003	0.025		1.04	0.30				0.069		
Dry rotary kiln	Clinker	5,106	11.03	0.65	0.017	0.15		6.36	1.83				0.43		
Onsite grinding and mixing	Factory cement	8,012											2.83		
Cement plant (inc. other)	Factory cement	8,012	15.44	0.91	0.30	2.64		8.90	2.56				3.41		
Offsite grinding and mixing	Cement	1,389											0.52		
Other					0.27	2.43									
Sector	Cement	9,401	15.44	0.91	0.30	2.64		8.90	2.56				3.93		

Totals	Main output		Energy		SEC	
Process/system/site description	Output description	Output, kt	Direct fuels	Total	Direct fuels	Total
Unit		kt	PJ	PJ	GJ/t	GJ/t
Rotary kiln	Clinker	6,843	28.06	28.64	4.10	4.19
Rotary kiln with planetary cooling	Clinker	1,294	5.14	5.25	3.98	4.06
Dry rotary kiln with 4-stage PH	Clinker	1,447	5.92	6.05	4.09	4.18
Dry rotary kiln with 4-stage PH + PC	Clinker	1,923	7.08	7.24	3.68	3.77
Dry rotary kiln with 5-stage PH + PC	Clinker	1,737	6.34	6.49	3.65	3.74
Semi-wet rotary kiln	Clinker	919	4.73	4.81	5.15	5.24
Semi-dry rotary kiln	Clinker	818	3.28	3.35	4.01	4.10
Dry rotary kiln	Clinker	5,106	20.04	20.48	3.93	4.01
Onsite grinding and mixing	Factory cement	8,012		2.83		0.35
Cement plant (inc. other)	Factory cement	8,012	30.76		3.84	
Offsite grinding and mixing	Cement	1,389		0.52		0.37
Other			2.70			
Sector	Cement	9,401	30.76	34.68	3.27	3.69

Figure A-41: Energy and material data table for the UK cement sector: 2010 baseline, GCV

NCV and mass - specific	Main output		Energy inputs											Energy outputs	
Site description	Roadmap ID	Output, kt	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Unit		kt	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Cement plant (inc. other)	-	8,012	1.83	0.11	0.033	0.31		1.00	0.29				0.43		
MEA Post-comb.	1c	8,012	7.34	0.11	0.033	0.31		1.00	0.29	4.27		1.28	0.053	4.27	1.28
MEA post-comb. over-the-fence-steam	2c	8,012	1.83	0.11	0.033	0.31		1.00	0.29		4.27		0.74		
KS-1 Post-comb.	3c	8,012	5.96	0.11	0.033	0.31		1.00	0.29	3.20		0.96	0.076	3.20	0.96
Oxyfuel (PC only)	4c	8,012	1.86	0.11	0.033	0.31		1.00	0.29			0.020	0.74		0.020
Oxyfuel (PC only) - colocation	5c	8,012	1.87	0.11	0.033	0.31		1.00	0.29			0.020	0.45		0.020
Oxyfuel comb.	6c	8,012	2.56	0.11	0.033	0.31		1.00	0.29			0.020	1.02		0.020
Oxyfuel comb. - colocation	7c	8,012	2.58	0.11	0.033	0.31		1.00	0.29			0.020	0.62		0.020

NCV and mass - specific	Main output		Non-energy inputs										Non-energy outputs				Totals		Emissions summary					
Site description	Roadmap ID	Output	Limestone	Limestone (to cement)	Clinker	Gypsum	PFA and puzzolana	GGBFS	Other	Quartz	Olivine (or serpentine)	Alkaline activating solution	O_2	Clinker	Cement (inc. substitutes)	O_2	CO_2 (captured)	Direct fuels	Total	Capture efficiency	Onsite emission	Onsite avoidance	Total emission	Total avoidance
Unit		kt	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	GJ/t	GJ/t	%	kgCO2e/t c	%	kgCO2e/t c	%
Cement plant (inc. other)	-	8,012	1,076	47.60	854	47.74	49.87		0.69					854	1,000			3.57	4.00		749	-	810	-
MEA Post-comb.	1c	8,012	1,076	47.60	854	47.74	49.87		0.69					854	1,000		1,088	9.08	9.14	85%	192	74%	200	75%
MEA post-comb. over-the-fence-steam	2c	8,012	1,076	47.60	854	47.74	49.87		0.69					854	1,000		637	3.57	8.58	85%	112	85%	219	73%
KS-1 Post-comb.	3c	8,012	1,076	47.60	854	47.74	49.87		0.69					854	1,000		975	7.70	7.78	85%	172	77%	183	77%
Oxyfuel (PC only)	4c	8,012	1,076	47.60	854	47.74	49.87		0.69				156	854	1,000	156	466	3.60	4.34	62%	286	62%	393	52%
Oxyfuel (PC only) - colocation	5c	8,012	1,076	47.60	854	47.74	49.87		0.69				156	854	1,000	156	467	3.61	4.06	62%	286	62%	351	57%
Oxyfuel comb.	6c	8,012	1,076	47.60	854	47.74	49.87		0.69				260	854	1,000	260	778	4.30	5.33	95%	41	95%	189	77%
Oxyfuel comb. - colocation	7c	8,012	1,076	47.60	854	47.74	49.87		0.69				260	854	1,000	260	780	4.32	4.94	95%	41	95%	131	84%

Figure A-42: Energy and material data table for CCS technologies for the UK cement sector: 2010 baseline, NCV

NCV and mass - specific	Main output		Energy inputs											Energy outputs	
Process system description	Roadmap ID	Output, kt	Coal	Petroleum coke	Natural Gas	Petroleum	Biomass	Fossil waste	Biomass waste	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Steam (internally produced)	Electricity (autogenerated)
Unit		kt	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Sector	-	9,401	1.56	0.092	0.028	0.27		0.85	0.25				0.42		
Novacem (Novacem, UK)	1a	9,401	1.92	0.11	1.08	0.33	0.30						0.42		
E-crete (Zeobond, Australia)	2a	9,401				0.80							0.21		
Celitement (Celitment, Germany)	3a	9,401	1.28	0.075	0.72	0.22	0.20						0.20		
Aether (Lafarge, France)	4a	9,401	1.33	0.078	0.028	0.26		0.72	0.21				0.42		
Aether: Kiln	(4a)	6,843	1.82	0.11	0.003	0.025		1.00	0.29				0.085		

NCV and mass - specific	Main output		Non-energy inputs										Non-energy outputs				Totals		Emissions summary			
Process system description	Roadmap ID	Output	Limestone	Limestone (to cement)	Clinker	Gypsum	PFA and puzzolana	GGBFS	Other	Quartz	Olivine (or serpentine)	Alkaline activating solution	O_2	Clinker	Cement (inc. substitutes)	O_2	CO_2 (captured)	Direct fuels	Total	Onsite emission	Onsite avoidance	Total emission	Total avoidance
Unit		kt	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	GJ/t	GJ/t	kgCO2e/t c	%	kgCO2e/t c	%
Sector	-	9,401	917	40.56	728	40.68	46.60	140	4.30						1,000			3.05	3.46	638	-	699	-
Novacem (Novacem, UK)	1a	9,401									1,108				1,000			3.75	4.17	185	71%	245	65%
E-crete (Zeobond, Australia)	2a	9,401					120	362				518			1,000			0.80	1.01	65	90%	96	86%
Celitement (Celitment, Germany)	3a	9,401	231		183				85.58	500					1,000			2.49	2.69	291	54%	320	54%
Aether (Lafarge, France)	4a	9,401	680	40.56	728	38.24	46.60	140	186						1,000			2.63	3.05	502	21%	563	19%
Aether: Kiln	(4a)	6,843	935						249					1,000				3.24	3.32	661	-	673	-

Figure A-43: Energy and material data table for alternative process technologies for the UK cement sector: 2010 baseline, NCV

A7 The chemicals sector

A7.1 Statistical bridge

	PJ (GCV)	Comment	Source
DUKES energy	176.9		DECC (2013)
DUKES fuels	93.1		DECC (2013)
Ammonia prod. NG	10.1		ONS (2014)
Burning oil	9.3		ONS (2014)
LPG	7.0		ONS (2014)
Gas oil	-6.9	Difference between sources	ONS (2014), DECC (2013)
Cracker fuel gas	48.8	Calculated	Section 6.2.1.1
Fuels for heat export	34.8	Annex J1	DECC (2013)
Fuel for CHP elec	63.2	Table 7.8	DECC (2013)
Fuel for non-CHP elec	2.3	6% non-CHP autogeneration (table 1.9)	DECC (2014), DECC (2013)
Total fuels	261.6		
DUKES electricity demand	66.4		DECC (2013)
CHP gen.	-26.9	Table 7.8	DECC (2013)
Non-CHP gen.	-1.0	Table 1.9 generation efficiency	DECC (2014), DECC (2013)
Net elec	38.5		
DUKES heat import	17.4		DECC (2013)
CHP gen.	-53.8	Table 7.8	DECC (2013)
Internal use	23.5	After heat export with Table 7.8 generation efficiency	DECC (2013)
Net heat	-12.9		
Baseline energy	287.1		

Table A-192: Chemicals sector baseline energy statistics bridge 2010

Sector division	Absolute energy, PJ (GCV)				
	Fuel (inc. SC by-prod.)	Steam	Elec.	Direct energy	Primary energy
Sector	261 (310)	-23	27	266 (315)	327 (376)
Sector, exc. upstream	213 (262)	-13	38	238 (287)	321 (370)
Sector, modelled	36 (85)	12	19	67 (116)	105 (154)
Steam cracking	4 (53)	-4	1	1 (50)	2 (51)
SC feedstock prod.	11	0	0	11	11
Ammonia prod.	10	-3	1	7	8
Other chemical proce	11	19	17	47	83
Heat and power	165	-64	-39	62	-
Refineries	37	-10	-11	16	-
Chemicals	127	-54	-28	45	-
Other	61	29	48	137	222

Table A-193:Energy baseline summary of the UK chemicals sector, GCV of fuels

A7.2 Production estimations

Table A-194 lists the capacities and assumed load factors for the sector with sources. Data was sought to represent the base year (2010). Subsequent closures identified include the Grangemouth G4 steam cracker (320kt/yr ethylene; ~640kthvc/yr), the Fawley SC-2 cracker (125kt/yr ethylene; ~250kthvc/yr), the Winnington soda ash plant (~500kt/yr soda ash), and the Newton Aycliffe PVC plant (280ktpvc/yr).

	Sites	Capacity (applied load factor)	Capacity source	Load factor source
Lower olefins (HVC)	4	3,840 (73%)	ICIS (2013)	Estimated (DECC 2013a)
BTX	4	1,775 (73%)	ICIS (2013)	Petrochemicals Europe (2013)
Cyclohexane	1	330 (87%)	ICIS (2013)	Petrochemicals Europe (2013)
Acetic acid	1	520 (85%)	ICIS (2013)	Organics average
Styrene	1	60 (61%)	ICIS (2013)	Petrochemicals Europe (2013)
MMA	1	200 (85%)	ICIS (2013)	Organics average
Acrylonitrile	1	280 (71%)	ICIS (2013)	Petrochemicals Europe (2013)
VAM	1	300 (85%)	ICIS (2013)	Organics average
EDC	1	600 (70%)	ICIS (2013)	Petrochemicals Europe (2013)
VCM	1	300 (70%)	ICIS (2013)	Petrochemicals Europe (2013)
Formaldehyde	2	465 (85%)	ICIS (2013)	Organics average
LDPE resin	1	400 (80%)	ICIS (2013)	Petrochemicals Europe (2013)
LLDPE resin	1	280 (90%)	ICIS (2013)	Petrochemicals Europe (2013)
HDPE resin	1	320 (90%)	ICIS (2013)	Petrochemicals Europe (2013)
Polypropylene resin	2	495 (89%)	ICIS (2013)	Petrochemicals Europe (2013)
PVC resin	3	425 (85%)	ICIS (2013)	Organics average
PET resin	2	170 (85%)	ICIS (2013)	Organics average
HIPS	1	70 (85%)	ICIS (2013)	Organics average
PTA	1	500 (85%)	ICIS (2013)	Organics average
SBR resin	2	105 (85%)	ICIS (2013)	Organics average
Ammonia	2	950 (90%)	ICIS (2013)	Webb et al. (2012)
Nitric acid	2	1,400 (63%)	ICIS (2013)	Estimated
Soda ash	2	1,000 (50%)	European Commission (2007b)	USGS (2013)
Titanium dioxide	2	300 (85%)	ICIS (2013)	Organics average
Chlorine	1	746 (85%)	ICIS (2013)	Organics average
Hydrogen	1	32 (85%)	ICIS (2013)	Organics average
Oxygen	-	3,285 (75%)	Strahan (2013)	Estimated

Table A-194: Capacity and load factor estimations for 2010 production in the UK chemicals sector

Load factors were estimated for organics based on production and capacity data at the European level. Where data was not available for certain organic and inorganic chemicals, the average load factor for European organics was used. Production of HVCs and Ammonia was estimated based on feedstock data (DECC 2014b, ONS 2014b) and production of nitric acid was back-calculated from NO_2 emissions data (DECC 2014g).

A7.3 Technology roadmap projection model

The resource balances of processes were incorporated into a flexible projection model so that key variables are brought into control. The model was built in built in Microsoft Excel. Figure A-44 is a screenshot of the control interface for selected variables.

Variable	Input	Suggested	Unit/ choice	Notes
Biomass C-fix?	Y	Y	Y/N	
NCV?	Y	Y	Y/N	
BAT ? (or BPT)	Y	Y	Y/N	
General improvements	10%	10%	%	
Capture efficiency				
Petrochemicals	85%	85%	% (80-95%)	
Ammonia (process only)	99%	99%	% (95-100%)	
CHP	85%	85%	% (80-95%)	
CHP - energy penalty for CCS	20%	20%	% (10-30%)	
Elec/heat - credit basis?	N		Y/N	
CCS on process' CHP?	Y	Y	Y/N	For Retrofit Post-combustion CCS options
Autogen. with process change?	N	N	Y/N	

Figure A-44: Screenshot of chemicals technology projection model variable control interface

Figure A-45 displays the interface enabling the construction of roadmaps at 5 year intervals to 2050. The model, and projection analysis, begins at the base year 2010 from which site share and aggregate production has been updated annually to 2013. Cells shaded in grey are editable but this is not suggested for the generation of roadmaps as they reflect assumed technological unavailability or years past. Total production is not directly editable as this is the combined production of lower olefins, ammonia, and other chemicals production. Other chemicals production has not been updated due to a paucity of data. Roadmaps constructed in the model for the assessment in section 6.5 are shown in Figure A-46.

Chemicals roadmap design interface																														
	BPT/ BAT process	Fuel/feedstock substitution				Retrofit Post-combustion CCS								Process change								External								
		CHP		SC		1c	2c	3c	4c	5c	6c	7c	8c	1s	2s	3s	4s	5s	6s	7s	8s									
Year		Petro-chem CHP fuel switch	Other CHP fuel switch	Waste plastics naphtha cracking	Gas based fuel gas	SC: MEA w/ NGCC CHP	SC: MEA w/ NG boiler	SC: MEA w/ biomass boiler CHP	SC: MEA w/ NG boiler	SC: MEA w/ Biomass boiler	SMR: process stream	petro-chem CHP: post-comb.	Other CHP: post-comb.	OCM	MTO: coal w/CCS	MTO: ligno	FT naphtha: coal-ligno blend	FT naphtha: ligno	ETE: starch	ETE: sugar	ETE: ligno w/ ligno-CHP	Grid primary energy intensity change	Grid decarbonisation	2010 prod. total	2010 prod. - HVCs	2010 prod. - NH3	2010 prod. - other chem.	2010 prod. - Petrochem CHP	2010 prod. - other CHP
2010	0%	0.7%	1.3%	0%	55%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%
2011	0%	0.7%	1.3%	0%	54%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	97%	94%	66%	100%	99%	98%
2012	0%	0.7%	1.3%	0%	52%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	97%	83%	98%	100%	89%	98%
2013	0%	0.7%	1.3%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	98%	91%	98%	100%	89%	89%
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	13%	97%	86%	98%	100%	89%	89%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	11%	26%	97%	86%	98%	100%	89%	89%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	13%	46%	97%	86%	98%	100%	89%	89%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	0%	16%	59%	97%	86%	98%	100%	89%	89%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%	14%	69%	97%	86%	98%	100%	89%	89%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	49%	0%	13%	75%	97%	86%	98%	100%	89%	89%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	61%	0%	11%	80%	97%	86%	98%	100%	89%	89%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%	10%	85%	97%	86%	98%	100%	89%	89%

Figure A-45: Screenshot of chemicals technology projection model roadmap construction interface

Year	BPT / BAT process	Fuel/feedstock substitution				Retrofit Post-combustion CCS								Process change							
		CHP		SC		1c	2c	3c	4c	5c	6c	7c	8c	1s	2s	3s	4s	5s	6s	7s	8s
		Petro-chem CHP fuel switch	Other CHP fuel switch	Waste plastics naphtha cracking	Gas based fuel gas	SC: MEA w/ NGCC CHP	SC: MEA w/ NG boiler	SC: MEA w/ biomass boiler CHP	SC: MEA w/ NG boiler	SC: MEA w/ Biomass boiler	SMR: process stream	petro-chem CHP: post-comb.	Other CHP: post-comb.	OCM	MTO: coal w/CCS	MTO: ligno	FT naphtha: coal-ligno blend	FT naphtha: ligno	ETE: starch	ETE: sugar	ETE: ligno w/ ligno-CHP
BASE																					
2015	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	0%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BASELINE																					
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	2%	2%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	6%	6%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	8%	8%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	9%	9%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	10%	10%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA	Reasonable action																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS	Reasonable action with CCS (1c, 6c)																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	10%	0%	0%	0%	0%	10%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	33%	0%	0%	0%	0%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	70%	0%	0%	0%	0%	70%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	90%	0%	0%	0%	0%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	100%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS2	Reasonable action with CCS (2c, 6c)																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	10%	0%	0%	0%	10%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	33%	0%	0%	0%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	70%	0%	0%	0%	70%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	90%	0%	0%	0%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	100%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS3	Reasonable action with CCS (3c, 6c)																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	10%	0%	0%	10%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	33%	0%	0%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	70%	0%	0%	70%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	90%	0%	0%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	100%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS4	Reasonable action with CCS (4c, 6c)																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	10%	0%	10%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	33%	0%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	70%	0%	70%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	90%	0%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	100%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RA-CCS5	Reasonable action with CCS (5c, 6c)																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	10%	10%	16%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	33%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	70%	70%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	90%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RT	OCM transition																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	48%	0%	0%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	60%	0%	0%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%	0%	0%	0%	0%	0%	0%
RT2	Ligno-MTO transition																				
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%	0%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	48%	0%	0%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	60%	0%	0%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%	0%	0%	0%	0%

Figure A-46: Screenshot of chemicals technology projection model roadmap designs

Year	BPT / BAT process	Fuel/feedstock substitution				Retrofit Post-combustion CCS								Process change							
		CHP		SC		1c	2c	3c	4c	5c	6c	7c	8c	1s	2s	3s	4s	5s	6s	7s	8s
		Petro-chem CHP fuel switch	Other CHP fuel switch	Waste plastics naphtha cracking	Gas based fuel	SC: MEA w/ NGCC CHP	SC: MEA w/ NG boiler	SC: MEA w/ biomass boiler CHP	SC: MEA w/ NG boiler	SC: MEA w/ Biomass boiler	SMR: process stream	petro-chem CHP: post-comb.	Other CHP: post-comb.	OCM	MTO: coal w/CCS	MTO: ligno	FT naphtha: coal-ligno blend	FT naphtha: ligno	ETE: starch	ETE: sugar	ETE: ligno w/ ligno-CHP
RT3		Ligno FT naphtha transition																			
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	48%	0%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	60%	0%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%	0%	0%
RT4		Starch ETE transition																			
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	0%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	49%	0%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	61%	0%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%	0%
RT5		Sugar ETE transition																			
2015	5%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2020	15%	0%	0%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
2025	30%	4%	4%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	7%	0%
2030	45%	7%	7%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	0%
2035	60%	11%	11%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	0%
2040	75%	15%	15%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	49%	0%
2045	88%	18%	18%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	61%	0%
2050	100%	20%	20%	0%	53%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	67%	0%

Figure A- cont'd: Screenshot of chemicals technology projection model roadmap designs

A7.3.1 Other model outputs

The following outputs supplement the assessment outputs of chapter 6.

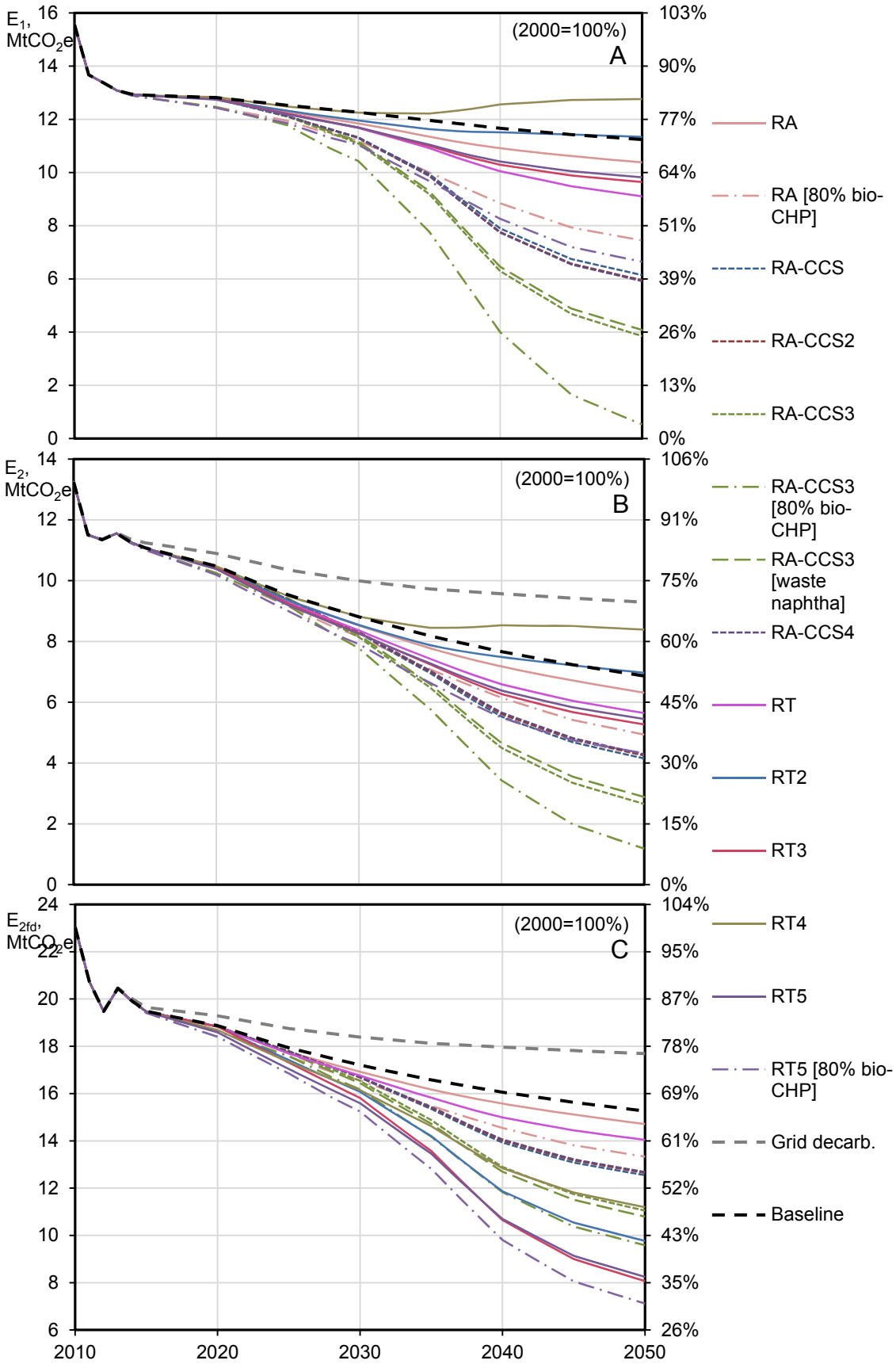

Figure A-47: Absolute GhG emission pathways of technology roadmaps for the UK chemicals sector – modelled sector

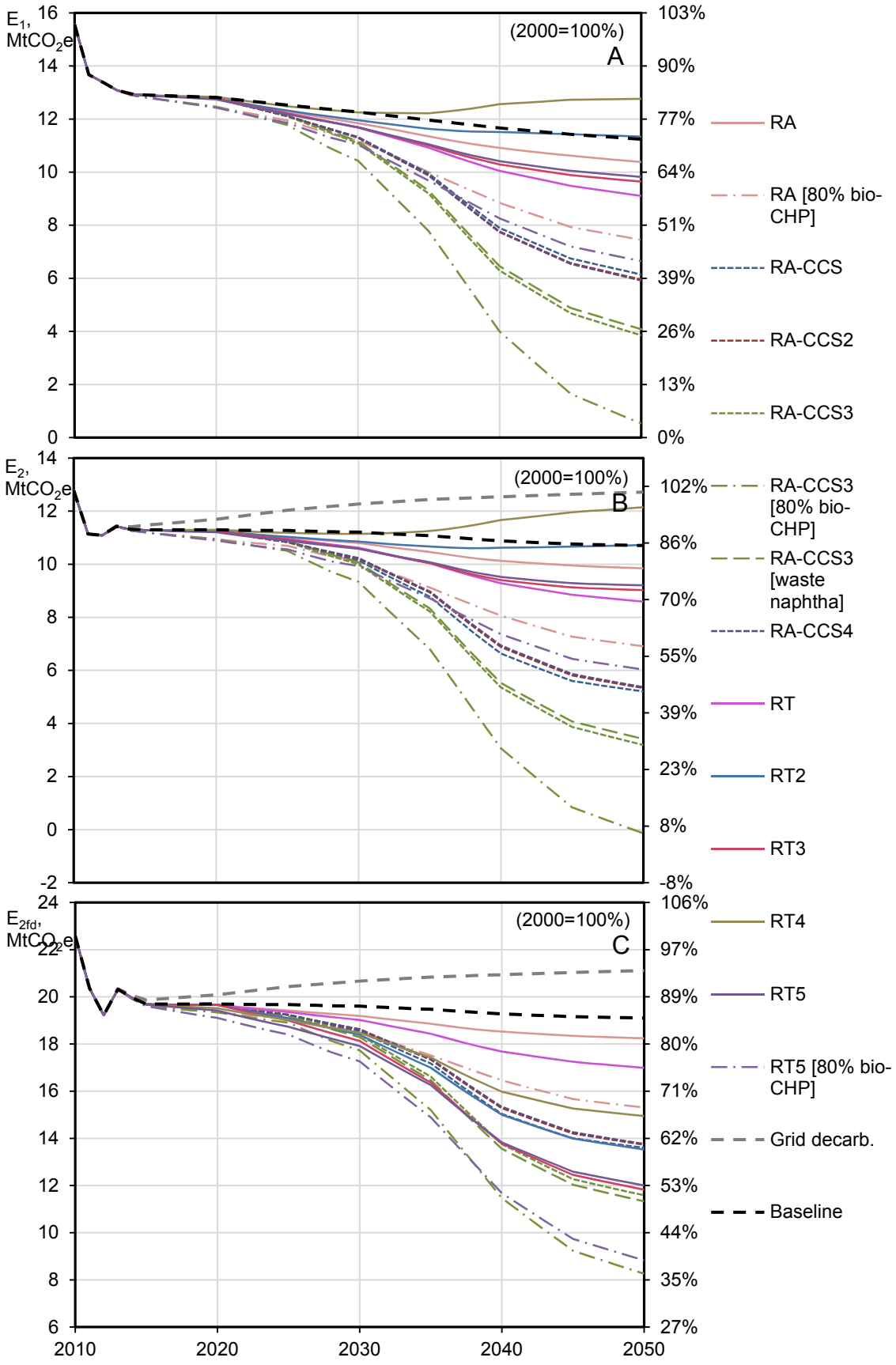

Figure A-48: Absolute GhG emission pathways of technology roadmaps for the UK chemicals sector – modelled sector (credit basis)

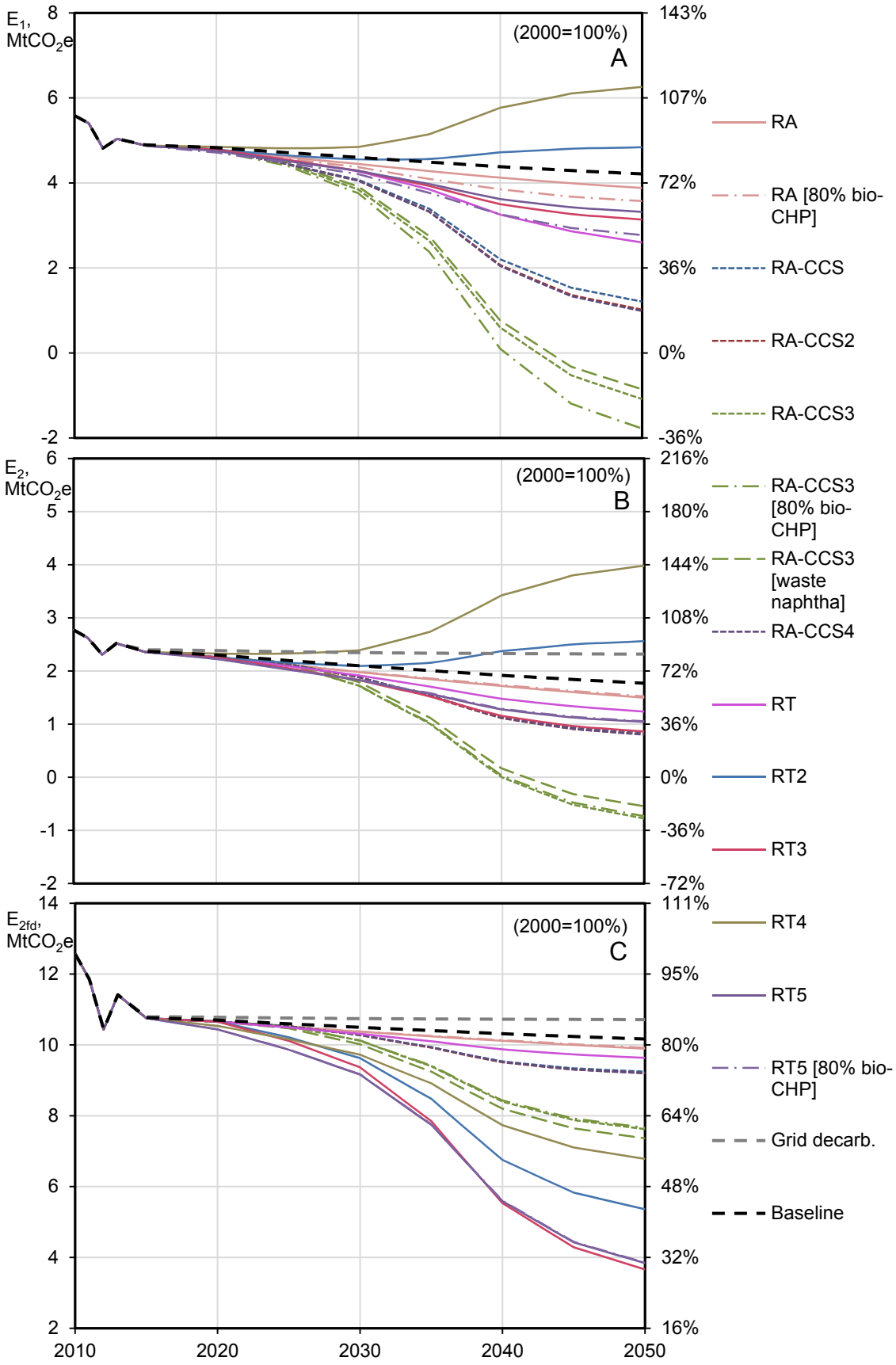

Figure A-49: Absolute GhG emission pathways of technology roadmaps for the UK chemicals sector – petrochemicals sector

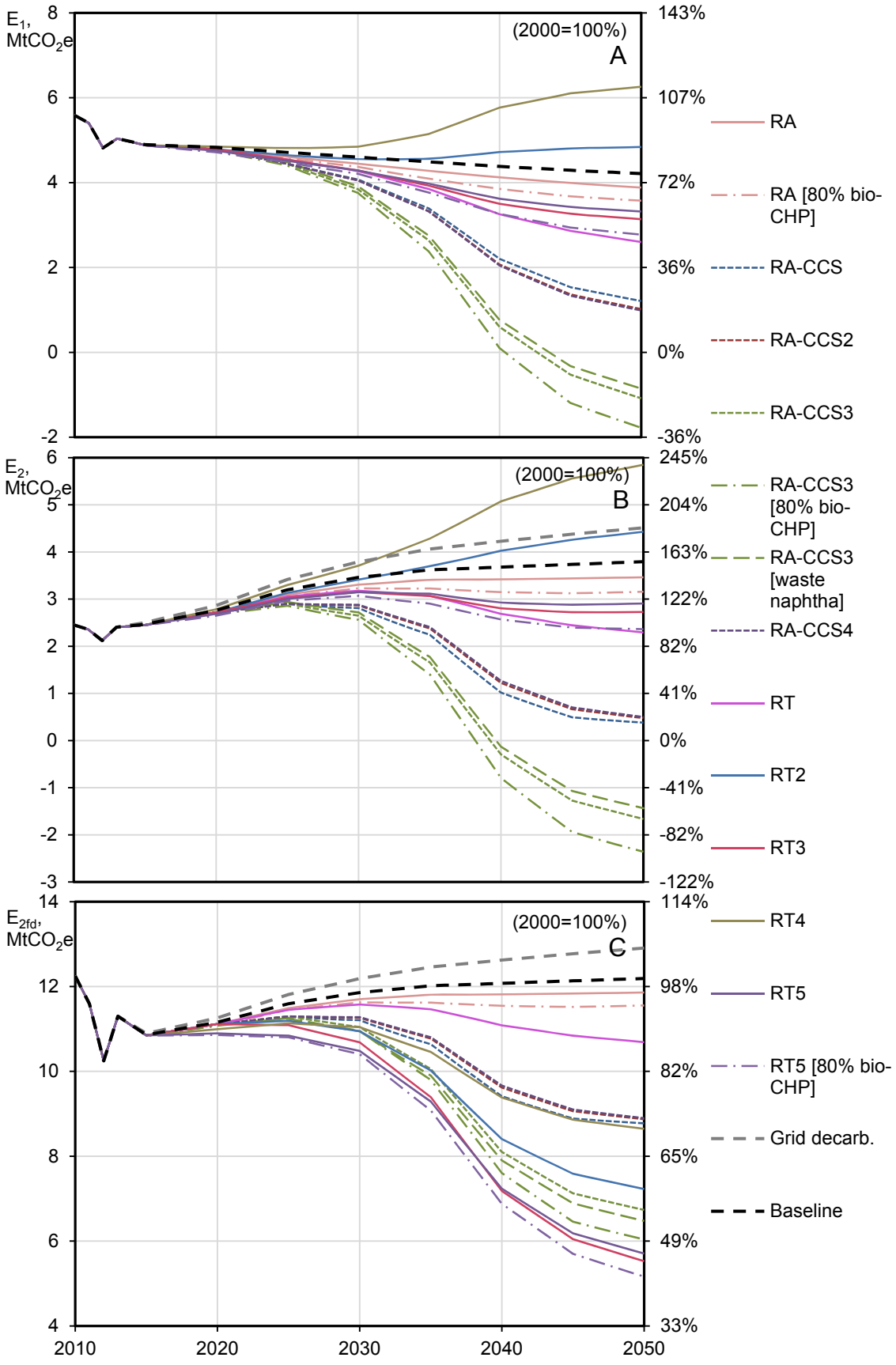

Figure A-50: Absolute GhG emission pathways of technology roadmaps for the UK chemicals sector – petrochemicals sector

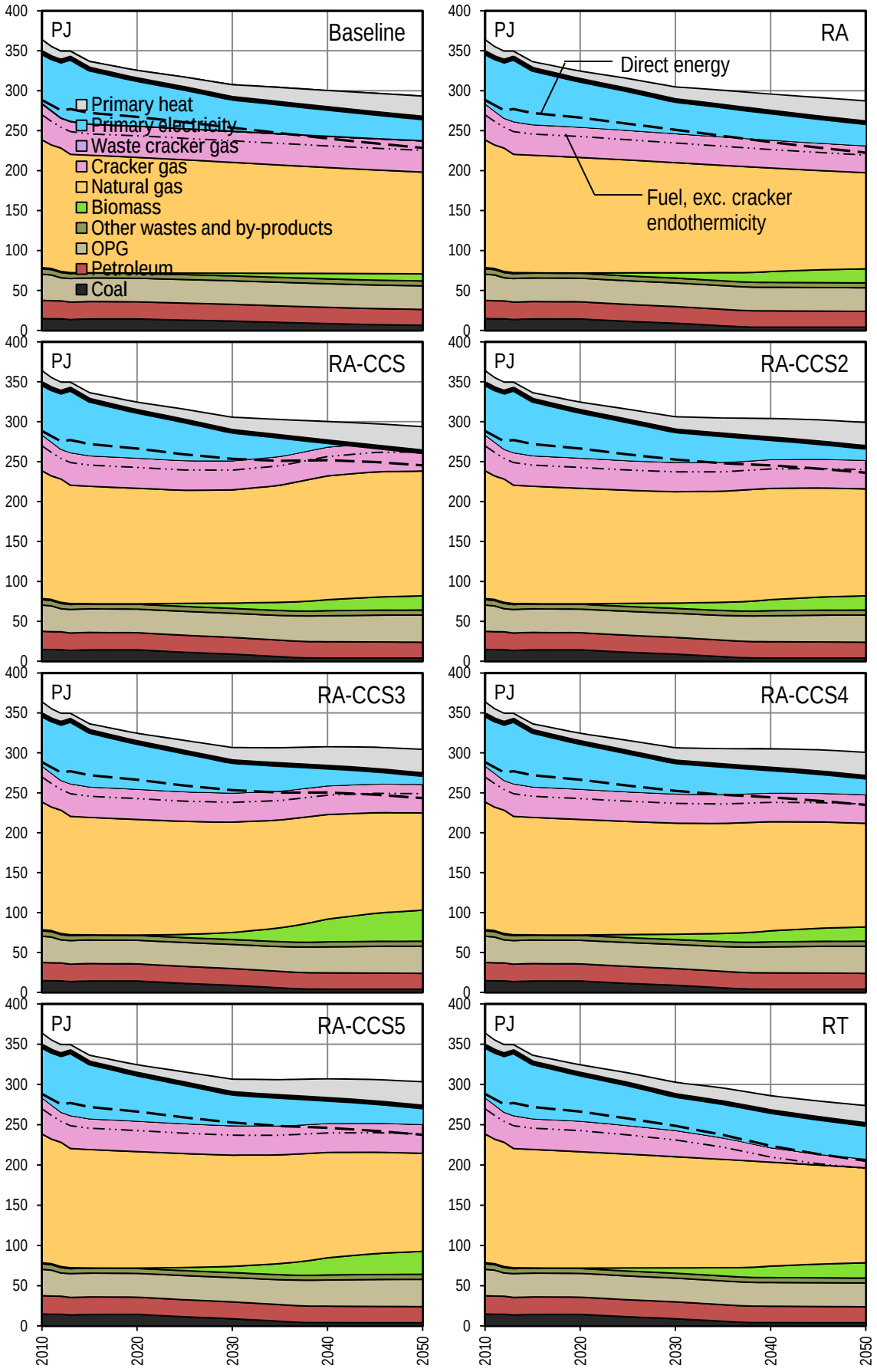

Figure A-51: Energy splits of technology roadmaps of the UK chemicals sector

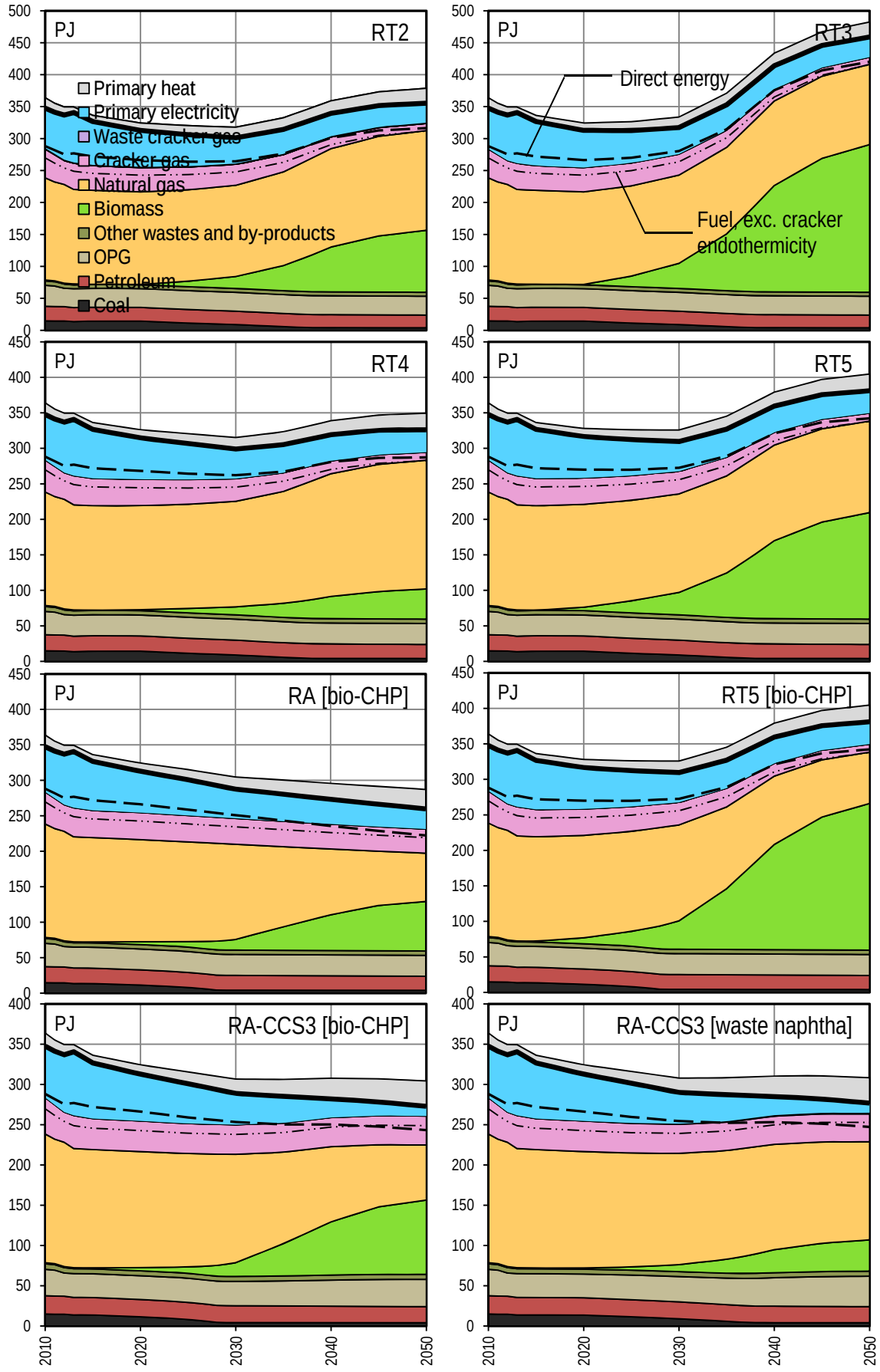

Figure A-cont'd: Energy splits of technology roadmaps of the UK chemicals sector

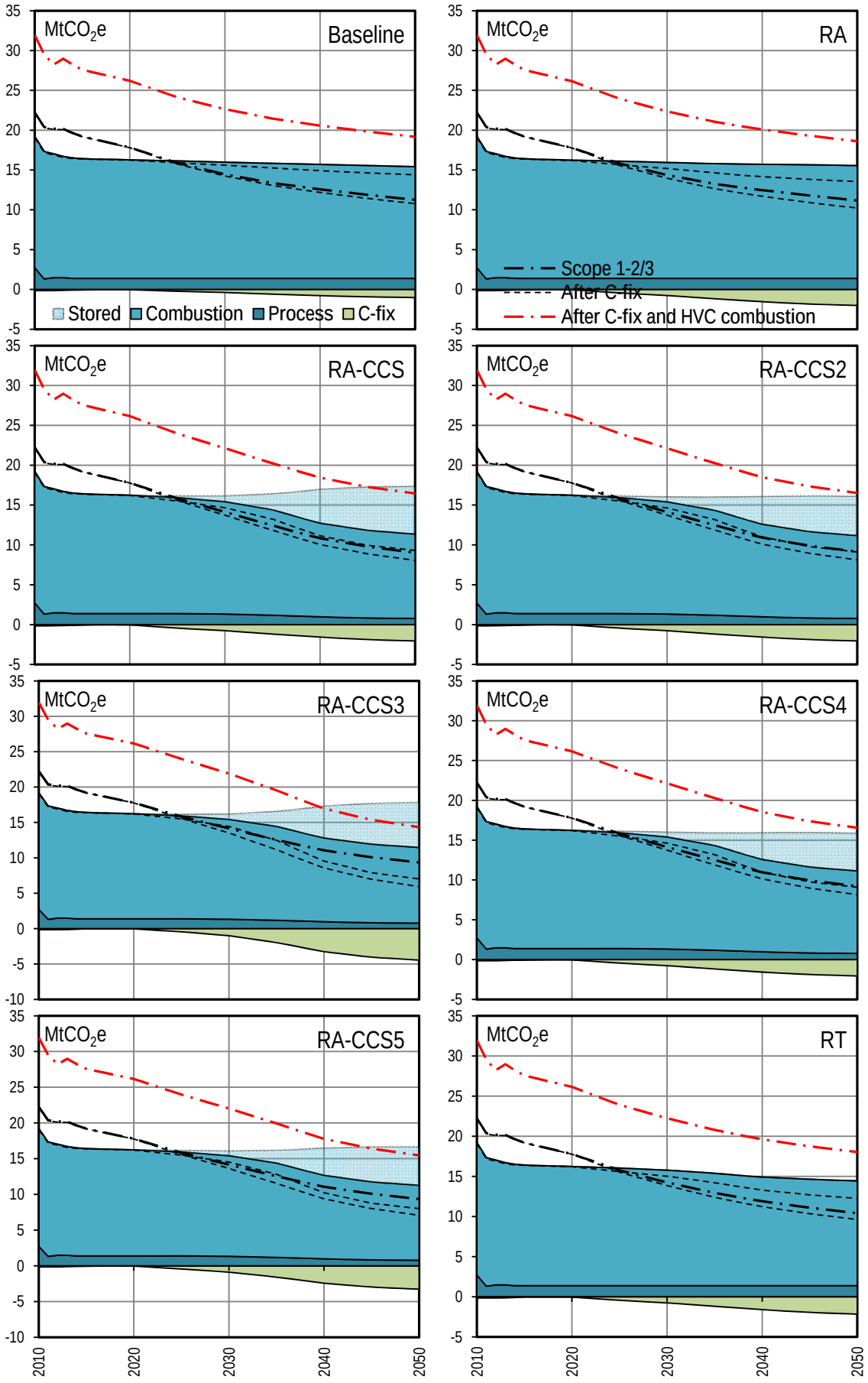

Figure A-52: GhG emissions splits of technology roadmaps of the UK chemicals sector

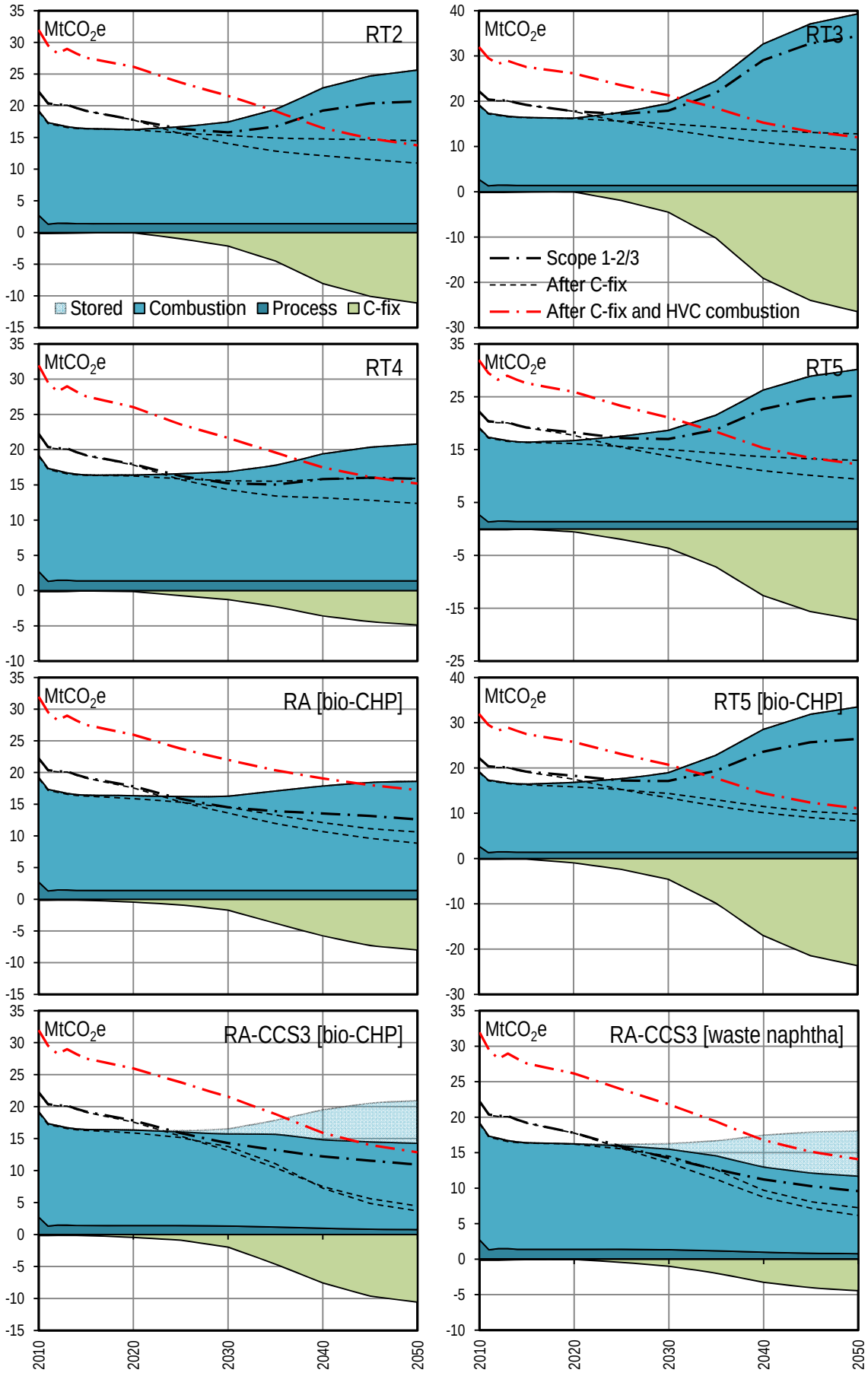

Figure A-cont'd: GhG emissions splits of technology roadmaps of the UK chemicals sector

Calorific value	Energy inputs															Energy outputs			
Resource	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Other wastes and by-products	Steam (internal)	Steam	Electricity (internal)	Electricity	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
Note/Source	DECC 2013	AEA 2012a	AEA 2012b	AEA 2012b	AEA 2012b	AEA 2012b	Ren 2009	Standard	Calculated	As cracker gas	AEA 2012b	Standard	Standard	Standard	Standard	Calculated	As cracker gas	Standard	Standard
Unit	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/kt	PJ/GWh	PJ/kt	PJ/kt	PJ/kt	PJ/GWh	PJ/GWh	PJ/GWh	PJ/GWh	PJ/kt	PJ/kt	PJ/GWh	PJ/GWh
NCV	0.0253	0.0477	0.0412	0.0430	0.0489	0.0453	0.0180	0.0557	0.0557	0.0557	0.0489	0.0036	0.0036	0.0036	0.0036	0.0557	0.0557	0.0036	0.0036
GCV	0.0266	0.0530	0.0433	0.0453	0.0527	0.0477	0.0200	0.0619	0.0600	0.0600	0.0527	0.0036	0.0036	0.0036	0.0036	0.0600	0.0600	0.0036	0.0036

Emissions Factors	Energy inputs															Energy outputs			
	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas - credit	Cracker fuel gas	Waste derived cracker gas	Other wastes and by-products	Steam (internal) -credit	Steam - credit	Electricity (internal) - credit	Electricity	Cracker fuel gas	Other	Steam (internal) - credit	Electricity (internal) - credit
Note/Source	Ren 2009	Ren 2009	AEA 2012	AEA 2012	IPCC 2006	AEA 2012		Ren 2009	Neelis 2003, cal	As cracker gas	Ren 2009	AEA 2012a	AEA 2012a	AEA 2012a	AEA 2012a	Neelis 2003,	As cracker gas	AEA 2012a	AEA 2012a
Unit	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ	MtCO2/PJ
GhG (per unit NCV)	0.0939	0.0561	0.0804	0.0812	0.0576	0.0674	0.0000	-0.0040	0.0452	0.0452	0.0574	0.0611	0.0611	0.1445	0.1445	0.0452	0.0452	0.0611	0.1445
Displacing imported	0.0939	0.0561	0.0804	0.0812	0.0576	0.0674	0.0000	-0.0040	0.0452	0.0452	0.0574	0.0611	0.0611	0.1445	0.1445	0.0452	0.0452	0.0611	0.1445

Figure A-53: General energy and emissions conversion factors used for analysis of the UK chemicals sector

A7.5 Material and energy tables

Figure A-54 is the energy (NCV) and material data table representing the baseline of the chemicals sector. For processes in which fuel split was not known, the fuel split of final sector fuel demand was used. The Sector 1 scope is limited to the statistical data obtained from the EA and the DUKES that refer specifically to the chemicals sector (SIC 20, 21). The Sector 2 scope includes additional items considered to be related to the chemicals sector from the refineries sector (19.2). The steam and electricity input figures at this level are highlighted in red as the ratio of import to internally generated demand has been adjusted proportionally with the higher amounts generated. Primary oil and natural gas feedstock used in the production of petrochemical feedstock is excluded from the account of material flows.

NCV and mass - 2010 baseline	Basic information						Energy inputs														Energy outputs			
Process description	Process sector	Output description	Output unit	Capacity	Load factor	Output	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Other wastes and by-products	Steam (internal)	Steam	Electricity (internal)	Electricity	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
							PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Processess modelled	Chemicals	Chemicals	kt	19,148	75%	14,397		21.38	1.09	0.01					45.25			16.26	7.92	3.18	15.43	45.25		12.19	
Steam cracking	Olefins	HVC	kt	3,840	73%	2,799		3.37							45.25					0.19	0.92	45.25		3.92	
BTX from reformate	Organics	BTX	kt	1,775	73%	1,294												2.78	1.36	0.02	0.11				
Chemical process	Organics	Cyclohexane	kt	330	87%	287																		0.37	
Chemical process	Organics	Acetic acid	kt	520	85%	440												1.69	0.82	0.08	0.37				
Chemical process	Organics	Styrene	kt	60	61%	37												0.23	0.11						
Chemical process	Organics	MMA	kt	200	85%	169		1.51	0.18	0.00								0.88	0.43	0.04	0.20				
Chemical process	Organics	Acrylonitrile	kt	280	71%	199		0.05	0.01	0.00										0.03	0.13			0.89	
Chemical process	Organics	VAM	kt	300	85%	254												0.82	0.40	0.16	0.76				
Chemical process	Organics	EDC	kt	600	70%	420		1.98	0.24	0.00										0.02	0.10				
Chemical process	Organics	VCM	kt	300	70%	210		0.67	0.08	0.00								0.07	0.03	0.03	0.12				
Chemical process	Organics	Formaldehyde	kt	465	85%	394														0.06	0.29			2.24	
Polymerisation	Polymers	LDPE resin	kt	400	80%	318												0.02	0.01	0.19	0.92				
Polymerisation	Polymers	LLDPE resin	kt	280	90%	252												0.49	0.24	0.04	0.19				
Polymerisation	Polymers	HDPE resin	kt	320	90%	288												0.27	0.13	0.05	0.24				
Polymerisation	Polymers	Polypropylene resin	kt	495	89%	441												0.30	0.14	0.08	0.37				
Polymerisation	Polymers	PVC resin	kt	425	85%	360		0.19	0.02	0.00								0.34	0.16	0.04	0.21				
Polymerisation	Polymers	PET resin	kt	170	85%	144		0.63	0.08	0.00										0.02	0.10				
Polymerisation	Polymers	HIPS	kt	70	85%	59		0.03	0.00	0.00										0.00	0.02				
Polymerisation	Polymers	PTA	kt	500	85%	423		0.19	0.02	0.00										0.03	0.14				
Polymerisation	Polymers	SBR resin	kt	105	85%	89												1.37	0.67	0.04	0.21				
Steam reforming (conventional)	Inorganics	Ammonia	kt	950	90%	857		9.10												0.12	0.57			3.34	
Otswald process	Inorganics	Nitric acid	kt	1,400	63%	884																		1.41	
Solvay process	Inorganics	Soda ash	kt	1,000	50%	500												3.99	1.94	0.03	0.12				
Chloride process	Inorganics	Titanium dioxide	kt	300	90%	270		3.12	0.38	0.00								2.12	1.03	0.25	1.23				
Mercury cell process	Inorganics	Chlorine	kt	746	70%	522												0.67	0.32	1.02	4.95				
Chemical process	Industrial g	Hydrogen	kt	32	75%	24		0.53	0.07	0.00								0.23	0.11	0.00	0.02				
Chemical process	Industrial g	Oxygen	kt	3,285	75%	2,464														0.65	3.15				
Non-CHP (autogeneration)	Energy trai	Electricity	GWh	315	90%	284	0.26	1.65	0.01	0.01			0.11												1.02
CHP	Energy trai	Electricity and he	GWh	24,922	90%	22,430	10.32	88.22	0.45	0.65		5.76	1.32				6.88							53.80	26.95
CHP - Wilton	Energy trai	Electricity and he	GWh	2,860	90%	2,574		11.87	0.05	0.07		0.66	0.15				0.79							6.17	3.09
CHP - Other	Energy trai	Electricity and he	GWh	22,062	90%	19,856	10.32	76.36	0.40	0.57		5.10	1.17				6.09							47.63	23.86
Unmodelled process and other	Undefined	Undefined	GWh				4.18	36.70	4.98	0.03		9.72			0.00			19.42	9.45	8.17	39.66	0.00			
Sector 1 - Chemicals only	Chemicals	Chemicals	kt	19,148	75%	14,397	14.75	148	6.53	0.70		15.47	1.44		45.25		6.88	35.68	17.37	11.34	55.09	45.25		65.98	27.97
Refinery for petrochemical feedstock	Refineries	Feedstock	kt	5,411	75%	4,069		2.01			8.37														
CHP/power - Grangemouth and Fawley	Refineries	Electricity and he	GWh		90%	5,834		9.89			24.50													9.92	11.08
Sector 2 - Chemicals and upstream	Chemicals	Chemicals/feeds	kt	24,559	75%	18,466	14.75	160	6.53	0.70	32.87	15.47	1.44		45.25		6.88	41.05	12.00	15.84	50.60	45.25		75.90	39.05

2010 Baseline: NCV and mass	Basic information						Material inputs												Energy totals								GhG totals					
Process description	Process sector	Output description	Output unit	Capacity	Load factor	Output	Naphtha	Gas oil	Ethane	Propane	Butane	Other cracker feedstock	Waste plastics	Natural gas	Methane	Methanol	Ethanol	Oxygen	Fuel	Heat	Electricity	Inputs	Fuel out	Heat out	Elec out	Outputs	Net	Direct comb.	Process	Total direct	Heat	Elec.	Total
							kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	kt	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e
Processess modelled	Chemicals	Chemicals	kt	19,148	75%	14,397	1,061	142	1,005	903	628	329		611					67.73	24.18	18.60	111	45.25	12.19		57.44	53.08	3.34	2.59	5.92	0.73	2.69	9.34
Steam cracking	Olefins	HVC	kt	3,840	73%	2,799	1,061	142	1,005	903	628	329							48.62		1.11	49.74	45.25	3.92		49.17	0.57	2.24		2.24	-0.24	0.16	2.16
BTX from reformate	Organics	BTX	kt	1,775	73%	1,294														4.14	0.13	4.27					4.27				0.25	0.02	0.27
Chemical process	Organics	Cyclohexane	kt	330	87%	287																		0.37		0.37	-0.37				-0.02		-0.02
Chemical process	Organics	Acetic acid	kt	520	85%	440								204						2.51	0.44	2.95					2.95				0.15	0.06	0.22
Chemical process	Organics	Styrene	kt	60	61%	37														0.34		0.34					0.34				0.02		0.02
Chemical process	Organics	MMA	kt	200	85%	169													1.69	1.30	0.24	3.23					3.23	0.10		0.10	0.08	0.03	0.21
Chemical process	Organics	Acrylonitrile	kt	280	71%	199													0.06		0.16	0.22		0.89		0.89	-0.68	0.00		0.00	-0.05	0.02	-0.03
Chemical process	Organics	VAM	kt	300	85%	254														1.22	0.91	2.13					2.13				0.07	0.13	0.21
Chemical process	Organics	EDC	kt	600	70%	420													2.23		0.13	2.35					2.35	0.13		0.13		0.02	0.15
Chemical process	Organics	VCM	kt	300	70%	210													0.76	0.11	0.15	1.01					1.01	0.04		0.04	0.01	0.02	0.07
Chemical process	Organics	Formaldehyde	kt	465	85%	394															0.35	0.35		2.24		2.24	-1.89				-0.14	0.05	-0.09
Polymerisation	Polymers	LDPE resin	kt	400	80%	318														0.03	1.11	1.15					1.15				0.00	0.16	0.16
Polymerisation	Polymers	LLDPE resin	kt	280	90%	252														0.73	0.23	0.96					0.96				0.04	0.03	0.08
Polymerisation	Polymers	HDPE resin	kt	320	90%	288														0.40	0.29	0.69					0.69				0.02	0.04	0.07
Polymerisation	Polymers	Polypropylene resin	kt	495	89%	441														0.44	0.44	0.88					0.88				0.03	0.06	0.09
Polymerisation	Polymers	PVC resin	kt	425	85%	360													0.22	0.50	0.25	0.97					0.97	0.01		0.01	0.03	0.04	0.08
Polymerisation	Polymers	PET resin	kt	170	85%	144													0.71		0.12	0.82					0.82	0.04		0.04		0.02	0.06
Polymerisation	Polymers	HIPS	kt	70	85%	59													0.03		0.02	0.05					0.05	0.00		0.00		0.00	0.01
Polymerisation	Polymers	PTA	kt	500	85%	423													0.21		0.17	0.38					0.38	0.01		0.01		0.02	0.04
Polymerisation	Polymers	SBR resin	kt	105	85%	89														2.04	0.25	2.28					2.28				0.12	0.04	0.16
Steam reforming (conventional)	Inorganics	Ammonia	kt	950	90%	857								358					9.10		0.69	9.79		3.34		3.34	6.45	0.51	0.96	1.47	-0.20	0.10	1.36
Otswald process	Inorganics	Nitric acid	kt	1,400	63%	884																		1.41		1.41	-1.41		1.32	1.32	-0.09		1.23
Solvay process	Inorganics	Soda ash	kt	1,000	50%	500														5.93	0.15	6.08					6.08		0.18	0.18	0.36	0.02	0.56
Chloride process	Inorganics	Titanium dioxide	kt	300	90%	270													3.51	3.16	1.49	8.15					8.15	0.21		0.21	0.19	0.21	0.61
Mercury cell process	Inorganics	Chlorine	kt	746	70%	522														0.99	5.97	6.96					6.96				0.06	0.86	0.92
Chemical process	Industrial gases	Hydrogen	kt	32	75%	24								49.09					0.60	0.34	0.03	0.97					0.97	0.04	0.13	0.17	0.02	0.00	0.19
Chemical process	Industrial gases	Oxygen	kt	3,285	75%	2,464															3.79	3.79					3.79					0.55	0.55
Non-CHP (autogeneration)	Energy trans.	Electricity	GWh	315	90%	284													2.06			2.06			1.02	1.02	1.03	0.13		0.13		-0.15	-0.01
CHP	Energy trans.	Electricity and heat	GWh	24,922	90%	22,430													114			114		53.80	26.95	80.75	32.85	6.94		6.94	-3.29	-3.90	-0.24
CHP - Wilton	Energy trans.	Electricity and heat	GWh	2,860	90%	2,574													13.59			13.59		6.17	3.09	9.26	4.33	0.78		0.78	-0.38	-0.45	-0.04
CHP - Other	Energy trans.	Electricity and heat	GWh	22,062	90%	19,856													100			100		47.63	23.86	71.48	28.52	6.16		6.16	-2.91	-3.45	-0.20
Unmodelled process and other	Undefined	Undefined	GWh																55.60	28.87	47.83	132	0.00			0.00	132	3.51	0.15	3.66	1.76	6.91	12.34
Sector 1 - Chemicals only	Chemicals	Chemicals	kt	19,148	75%	14,397	1,061	142	1,005	903	628	329		611					239	53.05	66.43	358	45.25	65.98	27.97	139	219	13.92	2.73	16.66	-0.79	5.56	21.42
Refinery for petrochemical feedstock	Refineries	Feedstock	kt	5,411	75%	4,069													10.38			10.38					10.38	0.60		0.60			0.60
CHP/power - Grangemouth and Fawley	Refineries	Electricity and heat	GWh		90%	5,834													34.39			34.39		9.92	11.08	21.00	13.39	1.97		1.97	-0.61	-1.60	-0.24
Sector 2 - Chemicals and upstream	Chemicals/feedstock	Chemicals/feedstock	kt	24,559	75%	18,466	1,061	142	1,005	903	628	329		611					284	53.05	66.43	403	45.25	75.90	39.05	160	243	16.48	2.73	19.22	-1.40	3.96	21.78

Figure A-54: Energy and material data table for the UK chemicals sector: 2010 baseline, NCV and mass units

NCV and mass - 2010 baseline	Basic information						Energy inputs														Energy outputs			
Process description	Process sector	Output description	Output unit	Capacity	Load factor	Output	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Other wastes and by-products	Steam (internal)	Steam	Electricity (internal)	Electricity	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
							PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Processes modelled	Chemicals	Chemicals	kt	19,148	75%	14,397		23.76	1.15	0.01					48.76			16.26	7.92	3.18	15.43	48.76		12.19	
Steam cracking	Olefins	HVC	kt	3,840	73%	2,799		3.75							48.76					0.19	0.92	48.76		3.92	
BTX from reformate	Organics	BTX	kt	1,775	73%	1,294												2.78	1.36	0.02	0.11				
Chemical process	Organics	Cyclohexane	kt	330	87%	287																		0.37	
Chemical process	Organics	Acetic acid	kt	520	85%	440												1.69	0.82	0.08	0.37				
Chemical process	Organics	Styrene	kt	60	61%	37												0.23	0.11						
Chemical process	Organics	MMA	kt	200	85%	169		1.67	0.19	0.00								0.88	0.43	0.04	0.20				
Chemical process	Organics	Acrylonitrile	kt	280	71%	199		0.06	0.01	0.00										0.03	0.13			0.89	
Chemical process	Organics	VAM	kt	300	85%	254												0.82	0.40	0.16	0.76				
Chemical process	Organics	EDC	kt	600	70%	420		2.20	0.26	0.00										0.02	0.10				
Chemical process	Organics	VCM	kt	300	70%	210		0.75	0.09	0.00								0.07	0.03	0.03	0.12				
Chemical process	Organics	Formaldehyde	kt	465	85%	394														0.06	0.29			2.24	
Polymerisation	Polymers	LDPE resin	kt	400	80%	318												0.02	0.01	0.19	0.92				
Polymerisation	Polymers	LLDPE resin	kt	280	90%	252												0.49	0.24	0.04	0.19				
Polymerisation	Polymers	HDPE resin	kt	320	90%	288												0.27	0.13	0.05	0.24				
Polymerisation	Polymers	Polypropylene resi	kt	495	89%	441												0.30	0.14	0.08	0.37				
Polymerisation	Polymers	PVC resin	kt	425	85%	360		0.21	0.02	0.00								0.34	0.16	0.04	0.21				
Polymerisation	Polymers	PET resin	kt	170	85%	144		0.70	0.08	0.00										0.02	0.10				
Polymerisation	Polymers	HIPS	kt	70	85%	59		0.03	0.00	0.00										0.00	0.02				
Polymerisation	Polymers	PTA	kt	500	85%	423		0.21	0.02	0.00										0.03	0.14				
Polymerisation	Polymers	SBR resin	kt	105	85%	89												1.37	0.67	0.04	0.21				
Steam reforming (conventional)	Inorganics	Ammonia	kt	950	90%	857		10.11												0.12	0.57			3.34	
Otswald process	Inorganics	Nitric acid	kt	1,400	63%	884																		1.41	
Solvay process	Inorganics	Soda ash	kt	1,000	50%	500												3.99	1.94	0.03	0.12				
Chloride process	Inorganics	Titanium dioxide	kt	300	90%	270		3.47	0.40	0.00								2.12	1.03	0.25	1.23				
Mercury cell process	Inorganics	Chlorine	kt	746	70%	522												0.67	0.32	1.02	4.95				
Chemical process	Industrial g	Hydrogen	kt	32	75%	24		0.59	0.07	0.00								0.23	0.11	0.00	0.02				
Chemical process	Industrial g	Oxygen	kt	3,285	75%	2,464														0.65	3.15				
Non-CHP (autogeneration)	Energy trai	Electricity	GWh	315	90%	284	0.28	1.84	0.01	0.02			0.13												1.02
CHP	Energy trai	Electricity and he	GWh	24,922	90%	22,430	10.86	98.03	0.48	0.68		6.06	1.47				7.41							53.80	26.95
CHP - Wilton	Energy trai	Electricity and he	GWh	2,859	90%	2,573		13.19	0.05	0.08		0.70	0.17				0.85							6.17	3.09
CHP - Other	Energy trai	Electricity and he	GWh	22,063	90%	19,857	10.86	84.84	0.42	0.60		5.36	1.30				6.56							47.63	23.86
Unmodelled process and other	Undefined	Undefined	GWh				4.40	40.78	5.24	0.03		10.23						19.42	9.45	8.17	39.66				
Sector 1 - Chemicals only	Chemicals	Chemicals	kt	19,148	75%	14,397	15.53	164	6.87	0.74		16.29	1.60		48.76		7.41	35.68	17.37	11.34	55.09	48.76		65.98	27.97
Refinery for petrochemical feedstock	Refineries	Feedstock	kt	5,411	75%	4,069		2.24			9.02														
CHP/power - Grangemouth and Fawley	Refineries	Electricity and he	GWh		90%	5,834		10.99			26.40													9.92	11.08
Sector 2 - Chemicals and upstream	Chemicals	Chemicals/feeds	kt	24,559	75%	18,466	15.53	178	6.87	0.74	35.42	16.29	1.60		48.76		7.41	41.05	12.00	15.84	50.60	48.76		75.90	39.05

2010 Baseline: NCV and mass	Basic information						Energy totals									GhG totals					
Process description	Process sector	Output description	Output unit	Capacity	Load factor	Output	Fuel	Heat	Electricity	Inputs	Fuel out	Heat out	Elec out	Outputs	Net	Direct comb.	Process	Total direct	Heat	Elec.	Total
							PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e	MtCO2e
Processes modelled	Chemicals	Chemicals	kt	19,148	75%	14,397	73.68	24.18	18.60	116	48.76	12.19		60.95	55.52	3.31	2.59	5.90	0.73	2.69	9.32
Steam cracking	Olefins	HVC	kt	3,840	73%	2,799	52.51		1.11	53.62	48.76	3.92		52.68	0.94	2.21		2.21	-0.24	0.16	2.14
BTX from reformate	Organics	BTX	kt	1,775	73%	1,294		4.14	0.13	4.27					4.27				0.25	0.02	0.27
Chemical process	Organics	Cyclohexane	kt	330	87%	287						0.37		0.37	-0.37				-0.02		-0.02
Chemical process	Organics	Acetic acid	kt	520	85%	440		2.51	0.44	2.95					2.95				0.15	0.06	0.22
Chemical process	Organics	Styrene	kt	60	61%	37		0.34		0.34					0.34				0.02		0.02
Chemical process	Organics	MMA	kt	200	85%	169	1.87	1.30	0.24	3.41					3.41	0.10		0.10	0.08	0.03	0.21
Chemical process	Organics	Acrylonitrile	kt	280	71%	199	0.07		0.16	0.22		0.89		0.89	-0.67	0.00		0.00	-0.05	0.02	-0.03
Chemical process	Organics	VAM	kt	300	85%	254		1.22	0.91	2.13					2.13				0.07	0.13	0.21
Chemical process	Organics	EDC	kt	600	70%	420	2.46		0.13	2.59					2.59	0.13		0.13		0.02	0.15
Chemical process	Organics	VCM	kt	300	70%	210	0.84	0.11	0.15	1.09					1.09	0.04		0.04	0.01	0.02	0.07
Chemical process	Organics	Formaldehyde	kt	465	85%	394			0.35	0.35		2.24		2.24	-1.89				-0.14	0.05	-0.09
Polymerisation	Polymers	LDPE resin	kt	400	80%	318		0.03	1.11	1.15					1.15				0.00	0.16	0.16
Polymerisation	Polymers	LLDPE resin	kt	280	90%	252		0.73	0.23	0.96					0.96				0.04	0.03	0.08
Polymerisation	Polymers	HDPE resin	kt	320	90%	288		0.40	0.29	0.69					0.69				0.02	0.04	0.07
Polymerisation	Polymers	Polypropylene resin	kt	495	89%	441		0.44	0.44	0.88					0.88				0.03	0.06	0.09
Polymerisation	Polymers	PVC resin	kt	425	85%	360	0.24	0.50	0.25	0.99					0.99	0.01		0.01	0.03	0.04	0.08
Polymerisation	Polymers	PET resin	kt	170	85%	144	0.78		0.12	0.89					0.89	0.04		0.04		0.02	0.06
Polymerisation	Polymers	HIPS	kt	70	85%	59	0.03		0.02	0.06					0.06	0.00		0.00		0.00	0.01
Polymerisation	Polymers	PTA	kt	500	85%	423	0.23		0.17	0.40					0.40	0.01		0.01		0.02	0.04
Polymerisation	Polymers	SBR resin	kt	105	85%	89		2.04	0.25	2.28					2.28				0.12	0.04	0.16
Steam reforming (conventional)	Inorganics	Ammonia	kt	950	90%	857	10.11		0.69	10.80		3.34		3.34	7.46	0.51	0.96	1.47	-0.20	0.10	1.36
Otswald process	Inorganics	Nitric acid	kt	1,400	63%	884						1.41		1.41	-1.41		1.32	1.32	-0.09		1.23
Solvay process	Inorganics	Soda ash	kt	1,000	50%	500		5.93	0.15	6.08					6.08		0.18	0.18	0.36	0.02	0.56
Chloride process	Inorganics	Titanium dioxide	kt	300	90%	270	3.88	3.16	1.49	8.52					8.52	0.21		0.21	0.19	0.21	0.61
Mercury cell process	Inorganics	Chlorine	kt	746	70%	522		0.99	5.97	6.96					6.96				0.06	0.86	0.92
Chemical process	Industrial gases	Hydrogen	kt	32	75%	24	0.66	0.34	0.03	1.03					1.03	0.04	0.13	0.17	0.02	0.00	0.19
Chemical process	Industrial gases	Oxygen	kt	3,285	75%	2,464			3.79	3.79					3.79					0.55	0.55
Non-CHP (autogeneration)	Energy trans.	Electricity	GWh	315	90%	284	2.27			2.27			1.02	1.02	1.25	0.13		0.13		-0.15	-0.01
CHP	Energy trans.	Electricity and heat	GWh	24,922	90%	22,430	125			125		53.80	26.95	80.75	44.24	6.94		6.94	-3.29	-3.90	-0.24
CHP - Wilton	Energy trans.	Electricity and heat	GWh	2,859	90%	2,573	15.03			15.03		6.17	3.09	9.26	5.77	0.78		0.78	-0.38	-0.45	-0.04
CHP - Other	Energy trans.	Electricity and heat	GWh	22,063	90%	19,857	110			110		47.63	23.86	71.48	38.47	6.16		6.16	-2.91	-3.45	-0.20
Unmodelled process and other	Undefined	Undefined	GWh				60.67	28.87	47.83	137					137	3.51	0.15	3.66	1.76	6.91	12.34
Sector 1 - Chemicals only	Chemicals	Chemicals	kt	19,148	75%	14,397	262	53.05	66.43	381	48.76	65.98	27.97	143	238	13.90	2.73	16.63	-0.79	5.56	21.40
Refinery for petrochemical feedstock	Refineries	Feedstock	kt	5,411	75%	4,069	11.26			11.26					11.26	0.60		0.60			0.60
CHP/power - Grangemouth and Fawley	Refineries	Electricity and heat	GWh		90%	5,834	37.39			37.39		9.92	11.08	21.00	16.39	1.97		1.97	-0.61	-1.60	-0.24
Sector 2 - Chemicals and upstream	Chemicals/feedstock	Chemicals/feedstock	kt	24,559	75%	18,466	310	53.05	66.43	430	48.76	75.90	39.05	164	266	16.46	2.73	19.19	-1.40	3.96	21.76

Figure A-55: Energy and material data table for the UK chemicals sector: 2010 baseline, GCV

NCV and mass - specific	Basic information		Energy inputs															Energy outputs			
Process system description	Roadmap ID	Output	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Wastes and other	Steam (internal)	Steam	Electricity (internal)	Electricity	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
		kt	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
OCM I (DCM)	1s	2,799		4.00						17.00							3.00				
Coal MTO I w/CCS (recycling and large cogen.)	2s	2,799	46.86																		
Ligno MTO	3s	2,799		18.95					48.84												
Coal ligno FT naphtha SC	4s	2,799	46.27						30.40												
Ligno FT naphtha SC I (small cogen.)	5s	2,799							133												
Maize starch ETE	6s	2,799		34.79					14.75												
Sugar cane ETE	7s	2,799		2.00					81.97												
Ligno ETE I (small cogen.)	8s	2,799		8.56					52.46												

NCV and mass - specific	Basic information		Material inputs													Mat. out	Totals		
Process system description	Roadmap ID	Output	Naphtha	Gas oil	Ethane	Propane	Butane	Other cracker feedstock	Waste plastics	Natural gas	Methane	Methanol	Ethanol	Oxygen	TBC	CO2 (captured)	Direct fuel inputs	Electricity	Net
		kt	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	GJ/t	GJ/t	GJ/t
OCM I (DCM)	1s	2,799									2,000			4,400			21.00	3.00	24.00
Coal MTO I w/CCS (recycling and large cogen.)	2s	2,799										2,326				3,741	46.86		46.86
Ligno MTO	3s	2,799											2,326				67.79		67.79
Coal ligno FT naphtha SC	4s	2,799	1,333														76.67		76.67
Ligno FT naphtha SC I (small cogen.)	5s	2,799											1,333				133		133
Maize starch ETE	6s	2,799											1,639				49.54		49.54
Sugar cane ETE	7s	2,799											1,639				83.97		83.97
Ligno ETE I (small cogen.)	8s	2,799											1,639				61.02		61.02

Figure A-56: Energy and material data table for alternative process technologies for the UK chemicals sector: NCV and mass units

NCV and mass - specific	Basic information		Energy inputs														Energy outputs			
Process system description	Roadmap ID	Output	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Wastes and other	Steam (internal)	Steam	Electricity (internal)	Electricity	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
		kt	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
OCM I (DCM)	1s	2,799		4.00						17.00							3.00				
Coal MTO I w/CCS (recycling and large cogen.)	2s	2,799	46.86																		
Ligno MTO	3s	2,799		18.95					48.84												
Coal ligno FT naphtha SC	4s	2,799	46.27	46.67					30.40												25.33
Ligno FT naphtha SC I (small cogen.)	5s	2,799		22.67					139												16.00
Maize starch ETE	6s	2,799		34.79					14.75												
Sugar cane ETE	7s	2,799		13.48					100												16.39
Ligno ETE I (small cogen.)	8s	2,799		16.75					52.46												4.92

NCV and mass - specific	Basic information		Material inputs													Mat. out	Totals			
Process system description	Roadmap ID	Output	Naphtha	Gas oil	Ethane	Propane	Butane	Other cracker feedstock	Waste plastics	Natural gas	Methane	Methanol	Ethanol	Oxygen	TBC	CO2 (captured)	Direct fuel inputs	Electricity	Elec out	Total
		kt	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	GJ/t	GJ/t	GJ/t	PJ
OCM I (DCM)	1s	2,799									2,000			4,400			21.00	3.00		24.00
Coal MTO I w/CCS (recycling and large cogen.)	2s	2,799										2,326				3,741	46.86			46.86
Ligno MTO	3s	2,799											2,326				67.79			67.79
Coal ligno FT naphtha SC	4s	2,799	1,333														123		25.33	98.00
Ligno FT naphtha SC I (small cogen.)	5s	2,799											1,333				162		16.00	146
Maize starch ETE	6s	2,799											1,639				49.54			49.54
Sugar cane ETE	7s	2,799											1,639				113		16.39	97.08
Ligno ETE I (small cogen.)	8s	2,799											1,639				69.21		4.92	64.30

Figure A-57: Energy and material data table for alternative process technologies for the UK chemicals sector: NCV and mass units, autogeneration included

NCV and mass - specific	Basic information		Energy inputs															Energy outputs			
Process system description	Process sector	Output description	Coal	Natural gas	Fuel oil	Gas oil	OPG	Misc. petroleum products	Biomass	OCM by-product gas	Cracker fuel gas	Waste derived cracker gas	Wastes and other	Steam (internally produced)	Steam (imported)	Electricity (autogenerated)	Electricity (grid)	Cracker fuel gas	Other	Steam (internal)	Electricity (internal)
		kt	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
UK SC w/ MEA CCS; NGCC CHP	1c	2,799		15.55							16.17			5.12		0.38	0.33			6.52	6.59
UK SC w/ MEA CCS; NG boiler and back-pressure turbine	2c	2,799		6.23							16.17			3.45		0.38	0.33			4.85	1.11
UK SC w/ MEA CCS; Biomass boiler and back-pressure turbine	3c	2,799		1.21					8.73		16.17			5.75		0.38	0.33			7.15	1.83
UK SC w/ MEA CCS; NG boiler	4c	2,799		4.56							16.17			3.16		0.38	0.33			4.56	
UK SC w/ MEA CCS; Biomass boiler	5c	2,799		1.21					4.45		16.17			4.18		0.38	0.33			5.58	

NCV and mass - specific	Basic information		Material inputs												Mat. out	Totals	
Process system description	Process sector	Output description	Ethane	Propane	LPG	Naptha	Gas oil	Refinery gas	Waste plastics	Natural gas	Methane	Methanol	Ethanol	Oxygen	TBC	CO2 (captured)	Direct fuel	Total
		kt	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	GJ/t	GJ/t
UK SC w/ MEA CCS; NGCC CHP	1c	2,799	379	50.88	359	323	224	118								1,366	31.72	24.44
UK SC w/ MEA CCS; NG boiler and back-pressure turbine	2c	2,799	379	50.88	359	323	224	118								921	22.40	20.59
UK SC w/ MEA CCS; Biomass boiler and back-pressure turbine	3c	2,799	379	50.88	359	323	224	118								1,533	26.11	23.58
UK SC w/ MEA CCS; NG boiler	4c	2,799	379	50.88	359	323	224	118								842	20.73	20.04
UK SC w/ MEA CCS; Biomass boiler	5c	2,799	379	50.88	359	323	224	118								1,115	21.82	21.13

Figure A-58: Energy and material data table for CCS technologies for the UK chemicals sector: NCV and mass units

A8 Energy intensive industry – other sectors

The so-called 'other sectors' include the sectors of pulp and paper, lime, glass, bricks (with some reference given to the wider ceramics sector in section 3.3), and aluminium. Background calculations and modelling are described in this section with some reference to the sectors of iron and steel, cement, and chemicals (specifically lower olefins and ammonia) as these were analysed alongside in sections 3.3 and 7.1.

A8.1 Historic trends

The sectors in the bottom-up assessment of section 3.3 were determined by assessing the relationship between SEC and physical output. Physical output was first obtained or estimated for each sector. For primary aluminium, output data was taken from the UK mineral database (Minerals UK 2014) while for the paper sector it was obtained from direct consultation with the CPI (2013). For bricks, output was determined by moving the 2010 tonnage reported for the CCA scheme *pro rata* with the trend in numbers of brick produced according to the BGS (British Geological Survey 2001, 2003, ONS 2011). Glass output trend was back-calculated from raw material process emission estimated for the UK GHGI (MacCarthy 2014), which assumes emissive raw material demand in the vast majority of glass product types and mass output (Webb et al. 2012). The same approach is applied to estimate the production trends lime (as was as ammonia in chapter 5).

For brick manufacture, present fuel mix was taken from a recent study by the Carbon Trust (2011) and combined with the SEC reported for the CCA scheme (World and Scott 2011). SEC was linearly extrapolated to the level in 1980 as reported by Langley (1984b). For glass, SEC was assumed to change with the trend in efficiency of glass furnaces reported by British Glass (2014) which is assumed to stay relevant to about 70% of sector energy demand. Fuel mix since 1990 is dominated by natural gas in both glass and bricks and assumed as the mix published in the EA (ONS 2014b) for glass and other ceramic products (SIC 23.1-4 and 23.7-9). SEC of paper making was extrapolated linearly from the baseline to that reported in 1980 and fuel mix changes informed by the EA with renewable fuel requirement informed by the Morgan (2013).

For primary aluminium, EA fuel data (ONS 2014b), which is dominated by the Lynmouth coal fired power plant and corroborated by data in the DUKES (DECC 2013a), was combined with historical average European smelting electricity SEC (World Aluminium 2014) to estimate electricity import after estimating demanded autogeneration from Lynmouth and Lochaber. Autogenerated demand from Lynmouth is given by the EA and at Lochaber generation approximately meets demand (Rio Tinto Alcan 2012). It is assumed that 95% of demand at Lochaber is met by its hydro-generators.

By comparison, ethylene SEC was also based on the European level (IEA 2009b) and this was assumed to have fallen steadily from the average in 1983 reported in (European Commission 1987). Thermal efficiency in steam cracking is influenced by the feedstock mix and this was adjusted for over time according to the relative performances stated by Neelis et al. (2003).

It was not possible to extrapolate Lime SEC to an earlier level so this was conservatively assumed to improve at a rate of 1% per annum from 1990 to the baseline. Fuel mix was inferred from the EA and has stayed reasonably constant over the period except for an increase in the use of waste fuels in recent years. Natural gas combustion is listed separately for ammonia production in the EA and this was used to represent energy demand for ammonia.

A8.2 Technology roadmap projection model

In this model outputs from the preceding projection models are imported and combined with the projection models of pulp and paper, lime, glass, and bricks. Figure A-59 shows the control interface for designing simple futures for the remaining sectors. Inputs apply to 2050 and the uptake path to 2050 follows a standard logistic 'S' curve. Figure A-60 shows the uptake figures to other roadmap designs.

Energy intensive industry roadmap projection										
	Production in 2010, kt	Production in 2013, kt	Production in 2050 (of 2013 level)	Process SEC improvement	Other SEC improvement	NG-fuel switch	Bio-fuel switch	Waste-fuel switch	Radical technology option	CCS option
Paper	4300	4400	100%	15%	-	-	40%	10%	0%	-
Lime	1559	1700	100%	15%	-	50%	33%	17%	-	-
Glass	3056	3000	100%	15%	10%	-	33%	-	-	-
Bricks	1350	1500	100%	15%	-	-	20%	20%	-	-
Iron and steel	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study
Cement	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study
Lower olefins	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study
Ammonia	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study	Sector study

Figure A-59: Screenshot of other sector technology projection model roadmap construction interface

A8.2.1 Other model outputs

Figure A-61 shows the GhG emission splits of RA roadmaps of each of the remaining energy intensive industrial sectors modelled over the period 1990-2050. The RT roadmap trend for pulp and paper is also shown for completion. Figure A-62 shows the associated energy splits.

	Production in 2013, kt	Production in 2050 (of 2013 level)	Process SEC improvement	Other SEC improvement	NG-fuel switch	Bio-fuel switch	Waste-fuel switch	Radical technology option	CCS option
	RA - Reasonable action								
Paper	4400	100%	15%	-	-	40%	10%	0%	-
Lime	1700	100%	15%	-	50%	33%	17%	-	-
Glass	3000	100%	15%	10%	-	33%	-	-	-
Bricks	1500	100%	15%	-	-	20%	20%	-	-
	RT - Radical transition								
Paper	4400	100%	15%	-	-	40%	10%	67%	-
Lime	1700	100%	15%	-	50%	33%	17%	-	-
Glass	3000	100%	15%	10%	-	33%	-	-	-
Bricks	1500	100%	15%	-	-	20%	20%	-	-
	Baseline								
Paper	4400	100%	10%	-	-	25%	10%	0%	-
Lime	1700	100%	10%	-	50%	17%	17%	-	-
Glass	3000	100%	10%	10%	-	17%	-	-	-
Bricks	1500	100%	10%	-	-	10%	10%	-	-
	Base								
Paper	4400	100%	0%	-	-	14%	1%	0%	-
Lime	1700	100%	0%	-	41%	0%	22%	-	-
Glass	3000	100%	0%	0%	-	0%	-	-	-
Bricks	1500	100%	0%	-	-	0%	0%	-	-

Figure A-60: Screenshot of other sector technology projection model roadmap designs

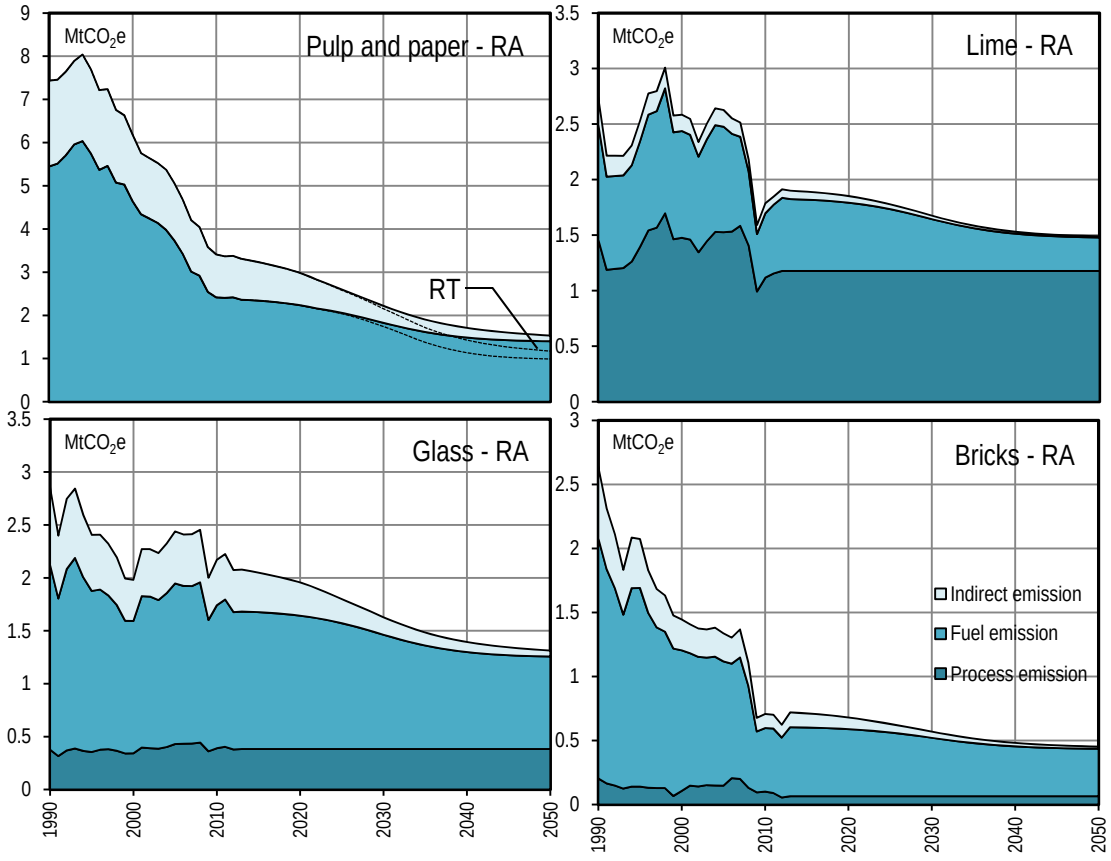

Figure A-61: GhG emissions splits of technology roadmaps of other UK energy intensive industries

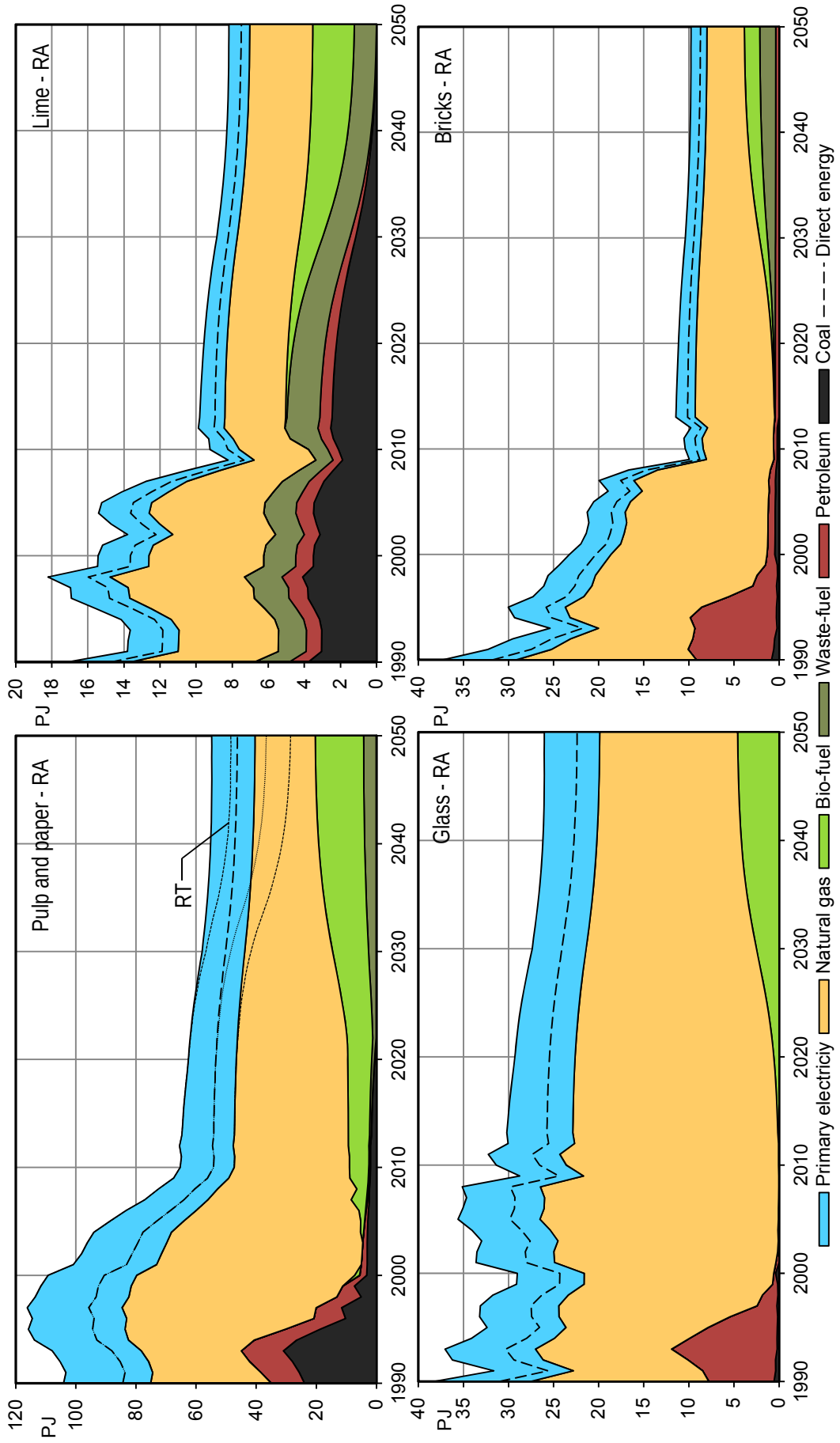

Figure A-62: Energy splits of technology roadmaps of other UK energy intensive industrial sectors

A9 Glossary

Ammonia (NH_3)	Ammonia is a compound of nitrogen and hydrogen. The most common production route is by steam reforming of methane into hydrogen followed by the synthesis of hydrogen with nitrogen from the air in what is known as the Haber process.
Baseline	The benchmark against which change is measured.
Blast furnace	The blast furnace is the most common furnace used in the primary production of iron. Iron ore is smelted in the presence of carbon, principally derived from coke, to produce iron. The blast furnace often describes the system which also encompasses ancillary equipment including hot-stoves, blowers, and by-product gas cleaning equipment.
Bottom-up	Bottom-up is the perspective from which individual processes and technologies are linked or aggregated into systems.
Calorific value (CV)	The calorific value, or heating value, of a fuel is defined as the amount of heat released when it is completely combusted and the products of the reaction are returned to the state of the reactants.
Capital expenditure (CAPEX)	Capital expenditure is money used for the acquirement or upgrade of physical assets. For example, the purchase of a new process plant or refurbishment of existing plant to extend its life.
Carbon sequestration	Carbon sequestration is typically the separation and storage, or usage, of carbon so as to prevent its emission into the atmosphere.
Combustion emission	Combustion emission is the emission of greenhouse gases from the combustion of carbon-based fuels.
Comparative abatement cost (AC) curve	A comparative AC curve is as a MAC curve but is used to visualise a comparison between alternatives as opposed to assessing a portfolio of additive options.
Crude steel	Crude steel is the total of usable ingots, continuously cast semi-finished products (slabs, billets and blooms) and liquid steel for castings. These forms follow from the production of liquid steel for which iron is reduced from iron ore and steel scrap is melted.

Decomposition analysis	Decomposition is a statistical analysis method in which the total change of some additive variable between multiple sources over time is split into contributory factors: aggregate output, structural change (relative source size), and user intensity (variable specific to size). Typically the variable is energy, the source is the industrial subsector, and size is measured by economic output.
Efficiency	Efficiency may be described as 'doing more with less' and is the desired output of a process divided by the required input.
Electric arc furnace (EAF)	The electric arc furnace is the most common furnace used in the secondary production of steel. Scrap is charged to the furnace and melted via the thermal energy released from an arc of electricity struck between two electrodes.
Energy	Energy is a thermodynamic concept that can be described as the ability to cause change. It comes in numerous forms including thermal, mechanical, chemical, electric and nuclear.
Energy efficiency	The energy efficiency of a process is measured as the desired output per energy input. Energy intensity is the reciprocal of energy efficiency.
Exergy	Exergy is the capacity of energy to perform work with reference to a specified thermodynamic state. This 'dead state' has thermodynamic equilibrium with the natural environment.
Final energy demand	Final energy demand is the energy demanded by the specified end-user or end-users.
Level	In process analysis the level describes the level of indirectness an input can have on a system, e.g. a first level analysis to a basic oxygen furnace (the system) may include the thermal energy carried by the input of hot molten iron and a second level analysis will include the direct energy inputs to the blast furnace that produced the iron, and so on.
Lower olefins	Lower olefins are petrochemical derivatives manufactured from the cracking feedstocks traditionally derived from oil or natural gas. They include ethylene, propylene, butadiene, and aromatics.
Marginal abatement cost (MAC) curve	A MAC curve is a graph that indicates the cost associated with the last unit (the marginal cost) of emission abatement for varying amounts of emission reduction.

Material efficiency	Material efficiency is an approach which encompasses a range of options for reducing primary production within an industrial system, while maintaining the same output of service from that system.
Multi-perspective decomposition	Multi-perspective decomposition is an approach to depicting the interrelationship between the measures of a projected baseline and those measures which go beyond the projected baseline. For example, relationship between the anticipated change in an industry's structure, fuel mix, and existing capital stock mix, with a speculated change brought about by the deployment of key replacement technologies.
Operational expenditure (OPEX)	Operational expenditure is the annual expenditure required to cover the ordinary running of production.
Ordinary Portland cement (OPC)	Ordinary Portland cement is the most common cement type. It is manufactured principally from limestone consists mainly of calcium silicate.
Pathway	A pathway is the profile of change of a specified variable over time.
Primary energy demand	Primary energy demand is the demand for energy that is drawn from natural raw materials and flows.
Process emission	Process emission is the emission of greenhouse gases from the processing of feedstock.
Process energy analysis (PA)	Process energy analysis is the analysis of energy required by a system constructed from the interlinked material flows of individual processes. The approach has conventions defined by the International Federation of Institutes of Advanced Studies (IFIAS).
Process flow diagram	A process flow diagram indicates the general flow of energy and/or materials between process plant and equipment.
Production cost	Production cost is the annualised cost of a product which takes into account all CAPEX and OPEX discounted to the present. It is equivalent to a product's break-even-price.
Radical	Radical, in the context of technological change, is the discontinuous progression of technology associated with the emergence of a new technological paradigm and development along a new technological trajectory.

Radical process change	Radical process change entails a substitution of the incumbent process with another process route to the same product, or with the process of a different product fulfilling the same service.
Roadmap	A roadmap is a planned set of actions to be delivered over a specified future period of time for the achievement of a particular goal. A technology roadmap is a plan for future technology deployment. A techno-economic roadmap is a technology roadmap that can also include economic measurement, criteria or goals.
Rotary cement kiln	The rotary cement kiln describes the process plant in which limestone is calcined and reacted with secondary materials to form clinker. This process typically uses a precalciner and some configuration of preheaters.
Sankey diagram	The Sankey diagram is a type of flow diagram in which the flows are represented by bands of width in proportion to a specified flow quantity, e.g. energy, exergy, or mass.
Scenario	A conceptualised future setting describing the outcome of some postulated event or set of events.
Soft-linking	Soft-linking is the linking of separately sourced top-down and bottom-up data. Typically this would involve the implantation of bottom-up data into top-down sectors leaving some remainder.
Statistical energy analysis (SEA)	Statistical energy analysis is the analysis of energy data disaggregated in statistical databases.
Steam cracker	The steam cracker is the process plant in which petrochemical feedstocks are cracked (broken down) into smaller hydrocarbons, primarily lower olefins. The feedstock is cracked by heating through the use of steam in pyrolysis furnaces.
Steam reformer	The steam reformer (specifically the steam methane reformer, or SMR) is the process plant in which hydrogen is separated from methane, with carbon dioxide produced as a by-product. The hydrogen may subsequently be used as a feedstock in the manufacture of ammonia.

Steelmaking Steelmaking describes the process system by which steel is manufactured. The level of system output may include, *inter alia*, liquid steel, semi-finished steel, or hot-rolled steel. The system may consist of a number of separate routes, each of which are themselves steelmaking systems.

System A system is an arbitrary specification defining the subject of analysis, e.g. the global cement industry, the UK steelmaking process, China. A system could describe an interlinked set of processes or an aggregation of disparate processes related by some other criterion.

Top-down Top-down is the perspective from which a system is divided into subparts.

Trajectory A trajectory is the direction of change of a specified variable over time.

Waterfall chart A waterfall chart is a visualisation of positive and negative contributory factors to a cumulative change of some quantity. It is one way in which the results of a decomposition analysis may be illustrated.

A10 Published paper reproductions

The papers are listed here in chronological order. The present author was the lead author of the first paper.

Griffin, P.W., Hammond, G.P., Ng, K.R. and Norman, J.B., 2012. Impact review of past UK public industrial energy efficiency RD&D programmes. Energy Conversion and Management, 60, pp. 243-250.

Griffin, P.W., Hammond, G.P. and Norman, J.B., 2014. Prospects for emissions reduction in the UK cement sector. Proceedings of Proceedings of the ICE - Energy, pp. 152-161.

Baruah, P., Eyre, N., Norman, J., Griffin, P. and Hammond, G., 2014. Firm-level perspective of Energy Efficiency Barriers and Drivers in UK Industry – Indications from an Online Survey. Behavior and Energy Efficiency Conference. Oxford.